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THE CAPACITY OF AGILITY AMONG UNTRAINED ADULTS AND AMONG MALE FORMER ELITE ATHLETES

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DOCTORAL DISSERTATION
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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I Manderoos SA, Vaara ME, Mäki PJ, Mälkiä EA, Aunola SK, Karppi S-L. A New Agility Test for Adults: Its Test-retest Reliability and Minimal Detectable Change in Untrained Women and Men Aged 28–55. J Strength Cond Res. 2016; 30(8):2226—2234.

II Manderoos S, Vaara M, Mälkiä E, Puukka P, Surakka J, Karppi S-L, Aunola S. Power of lower extremities is most important determinant of agility among physically inactive or active adult people. Physiother Res Int. 2018 Jul; 23(3):e1716. doi: 10.1002/pri.1716.

III Sirpa Manderoos, Niko S. Wasenius, Marja K. Laine, Urho M. Kujala, Esko A. Mälkiä, Jaakko Kaprio, Seppo Sarna, Heli M. Bäckmand, Jyrki A. Kettunen, Sirkka Aunola, Johan G. Eriksson. Power of lower extremities and age were the main determinants on the Agility Test for Adults in a cohort of men aged 66–91 years. Eur J Physiother. 2019; 1–10. doi:10.1080/21679169.2019.1650395

IV Manderoos S, Wasenius N, Laine MK, Kujala UM, Mälkiä E, Kaprio J, Sarna S, Bäckmand HM, Kettunen JA, Heinonen OJ, Jula AM, Aunola S, Eriksson JG. Mobility and muscle strength in male former elite endurance and power athletes aged 66–91 years. Scand J Med Sci Sports. 2017; 27(11):1283–1291.

The publications are referred to in the text by their roman numerals.

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ABBREVIATIONS

α	Cronbach's alpha
β	Multiple regression beta coefficient
1RM	One repetition maximum
20mRT	Twenty meters running time
ABC scale	Activities-specific Balance Confidence scale
ACSM	American College of Sports Medicine
ATA	Agility Test for Adults
BIA	Bioimpedance analysis
BMI	Body mass index
CI	Confidence interval
CMJ	Countermovement jump
CO_2	Carbon dioxide
CODS	Changes of direction and speed
COLD	Change of Lateral Direction Test
CSRT	Choice Stepping Reaction Time Test
CSA	Cross-sectional area
CT	Computed tomography
CV	Coefficient of variation
DLW	Doubly labelled water
DXA	Dual-energy x-ray absorptiometry
EE	Energy expenditure
EMG	Electromyography
ESST	Edgren Side Step Test
EWGSOP	European Working Group on Sarcopenia in Older People
FAT	Functional Ability Test
FIG8	Figure-of-Eight Running Test
FT	Fast-twitch
HHD	Hand-held dynamometry
IAT	Illinois Agility Test
ICC	Intraclass correlation coefficient
ICF	International Classification of Functioning, Disability and Health
kcal	Kilocalorie

KELA	Social Insurance Institution in Finland
LOA	Bland and Altman's 95% limits of agreement
LTPA	Leisure-time physical activity
MDC_{95}	Minimal detectable change at 95% confidence interval
MET	Metabolic equivalent of task
MET_c	Maximum oxygen consumption in MET (MET capacity)
MET_h	MET-hours
MET_{min}	MET-minutes
MRI	Magnetic resonance imaging
N	Newton
O_2	Oxygen
P	Power
PA	Physical activity
r	Correlation
R^2	Coefficient of determination
SD	Standard deviation
SE β	Standard error of beta coefficient
SEM	Standard error of measurement
SFT	Senior fitness test
SJT	Sargent jump test
SLJ	Standing long jump
SPC	Standardized principal component
SPPB	Short Physical Performance Battery
SRF	Self-rated fitness
SRH	Self-rated health
ST	Slow-twitch
SWC	Smallest worthwhile change
TEE	Total energy expenditure
TUG	Timed Up-and-Go Test
UG	Up-and-Go Test
VJ	Vertical jump
VO_2	Oxygen consumption
VO_{2max}	Maximum oxygen uptake
VSJ	Vertical squat jump
WHO	World Health Organization

ABSTRACT

The capacity of agility has been extensively studied in sport-specific contexts. Thus, there is a great need for understanding possible explanatory factors determining the capacity of agility and the meaning of agility in physical functioning in middle-aged and older people. The Agility Test for Adults (ATA) has been developed to assess the capacity of agility more comprehensively than previously used agility tests do. The main aims of this study were to evaluate 1) the test-retest reliability of the ATA and to quantify a clinically meaningful change (MDC_{95}), 2) the determinants of agility, 3) the feasibility of the ATA, and 4) the effects of participation in competitive sports in young adulthood or life-long LTPA on the present level of physical functioning. The International Classification of Functioning, Disability and Health (ICF) was used as a framework to define the measures of physical functioning.

The study includes three study cohorts. The first includes healthy untrained adults (n = 52, 25 women and 27 men) who participated in the reliability study. The second study cohort consists of 233 healthy participants (149 women and 84 men). The third includes 100 male former elite athletes (endurance n = 50, power n = 50) and 50 matched controls aged 66 to 91 years. Both objective measures and questionnaires-based data were used.

The high reliability scores of the ATA showed that it is stable and reliable in untrained adults. The magnitudes of the values identifying clinically meaningful changes in the ATA were small in both women and men. Jumping length was the main determinant of agility in women and men, whereas jumping height and age were the main determinants of the results of the ATA in a cohort of men aged 66-91 years. Data including elderly men allowed the evaluation of the feasibility of the ATA for people over sixty years old and with a large age distribution.

A former elite athletic career interrelated with greater explosive force production of the lower extremities at old age among former elite power athletes, which may partly be explained by participation in competitive power type sports from young age, and not by life-long LTPA.

The thesis provides recommendations for a reliable, responsive, and clinically useful measurement method of the ATA suitable for evaluating the capacity of agility in middle-aged and older adults. The ATA seems to be a more sensitive test to reveal physical disorders of a participant than the other commonly used mobility tests. By using responsive measures, it is possible to identify early decline in agility. Our data set also showed that lower limb muscle function measured by a test demanding explosive power plays an important role in maintaining or enhancing the capacity of agility.

TIIVISTELMÄ

Ketteryyttä on tutkittu paljon osana urheilijoiden suorituskykyä. Nyt tarvitaan tietoa ketteryyttä selittävistä tekijöistä ja sen merkityksestä fyysiseen toimintakykyyn keski-ikäisillä ja vanhemmilla henkilöillä. Aikuisten ketteryystesti on kehitetty arvioimaan ketteryyttä moniulotteisemmin kuin mitä aikaisimmilla ketteryystesteillä on kyetty arvioimaan. Tutkimuksen päätarkoituksena oli selvittää 1) Aikuisten ketteryystestin toistettavuutta ja arvioida kliinisesti pienin muutosarvo testisuorituksesta, 2) ketteryyttä selittäviä tekijöitä, 3) Aikuisten ketteryystestin soveltuvuutta sekä 4) nuoruusvuosina harjoitetun kilpaurheilun tai elämänikäisen fyysisen aktiivisuuden vaikutuksia fyysiseen toimintakykyyn. Toimintakyvyn, toimintarajoitteiden ja terveyden kansainvälistä luokitusta (ICF) on käytetty viitekehyksenä määritettäessä fyysisen toimintakyvyn mittareita.

Tutkimus koostuu kolmesta aineistosta. Aikuisten ketteryystestin toistettavuustutkimuksessa käytettiin aineistoa, jossa on keski-ikäisiä naisia (n = 25) ja miehiä (n = 27). Ketteryyttä selittäviä tekijöitä arvioivassa tutkimuksessa käytettiin kahta aineistoa, joista toisessa on keski-ikäisiä naisia (n = 149) ja miehiä (n = 84) ja toisessa on entisiä huippu-urheilijoita (n = 100) ja heidän verrokkejaan (n = 50). Aikuisten ketteryystestin soveltuvuutta arvioitiin viimeksi mainitulla aineistolla. Tutkimuksessa käytettiin sekä objektiivisia mittausmenetelmiä että kyselymittareita.

Aikuisten ketteryystesti osoittautui luotettavaksi ja vakaaksi testiksi arvioimaan ketteryyttä keski-ikäisillä naisilla ja miehillä. Kliinisesti merkitsevät muutosarvot ketteryyssuorituksissa jäivät alhaisiksi. Pituushyppy oli merkittävin ketteryyttä selittävä tekijä keski-ikäisillä naisilla ja miehillä, kun taas hyppykorkeus ja ikä selittivät parhaiten ketteryystestin suoritusaikojen vaihtelua 66–91-vuotiailla miehillä. Tämä iäkkäiden miesten aineisto osoitti Aikuisten ketteryystestin soveltuvan myös terveille 80-vuotiaille miehille. Alaraajojen suurempi räjähtävä voiman tuotto entisillä nopeusvoimaurheilijoilla kuin kestävyysurheilijoilla tai verrokkihenkilöillä selittynee todennäköisimmin nopeusvoimatyyppiseen kilpaurheiluun osallistumisesta nuoruusvuosina kuin elinikäisestä fyysisestä aktiivisuudesta.

Tämä väitöskirja esittää suosituksen luotettavasta, herkästä ja kliinisesti käyttökelpoisesta mittarista ketteryyden arviointiin keski-ikäisillä ja vanhemmilla henkilöillä. Aikuisten ketteryystesti näyttäisi olevan herkempi arvioimaan koehenkilöiden fyysisiä toimintakyvyn häiriöitä kuin muut käytössä olevat ketteryystestit. Käyttämällä herkempää mittaria on mahdollista tunnistaa ketteryysominaisuuksien heikentyminen jo varhaisvaiheessa. Tämä tutkimusaineisto osoitti myös, että alaraajojen räjähtävällä voimantuotolla on merkittävä osa ketteryysominaisuuksien ylläpitämisessä ja edistämisessä.

1 INTRODUCTION

Functioning refers to the human physical, psychological and social capacity to perform relevant and essential actions of everyday life. These include work, education, leisure time activities and hobbies, and taking care of oneself and others - in the environment where the individual lives. The conceptual framework for this study arises from the World Health Organization (WHO) model entitled 'The International Classification of Functioning, Disability and Health', also known as ICF [1]. This study focuses primarily on function of the lower extremities, which is one of the main indicators of mobility, and is also commonly used in clinical practice [2–5].

Agility has been extensively studied within a sport specific context [6–11]. However, physical characteristics that determine capacity of agility are poorly understood in untrained middle-aged people and in older persons after their athletic career. Some studies have shown that capacity of agility is required to execute activities of daily living in older adults independently and safely [12–14]. A measurement of agility should be connected with various evaluation methods of physical functioning to screen for early signs of declined capacity of agility, or to assess benefit from exercise on agility among middle-aged and elderly people.

The ability to successfully execute several physical tasks of daily living, such as rising from a chair, handling or carrying objects, walking, climbing stairs, or using public transport depends on the maintenance of muscle strength and muscle power of the lower extremities [15–18]. Ageing has been shown to associate with decreased maximal strength and explosive force production, especially in the early sixties, disturbing daily living [19–21].

In Finland, nearly one third of adults do not regularly participate in leisure time physical activity. More than half of Finnish women aged 75 years and above and 40% of men are physically inactive in their leisure time [22]. Regular physical activity (PA) positively influences the human physical, psychological and social health. Human beings need PA at all stages in the life cycle. In adults, proper PA enhances work performance [23, 24] and decreases the overall risk of several chronic diseases, particularly hypertension, type 2 diabetes, osteoporosis and cardiovascular diseases [25]. Regular PA has been shown to associate with better physical functioning [25, 26], to reduce risk of mobility limitation and to maintain functional independence among older adults [27].

The ICF model offers the standard framework and terminology for conceptualizing, measuring and reporting functioning [1] and categorizes outcomes according to 5 levels of human function: 1) 'body functions' describes e.g. the muscle functions of lower extremities, 2) 'activities' i.e. the execution of function by participant including the tests of mobility, 3) 'participation' includes measures of self-reported balance confidence for performing various daily activities, 4) 'personal factors' are the demographic background factors of the individual, like age and health status and 5) a research laboratory can be located in 'environmental factors' (Figure 1).

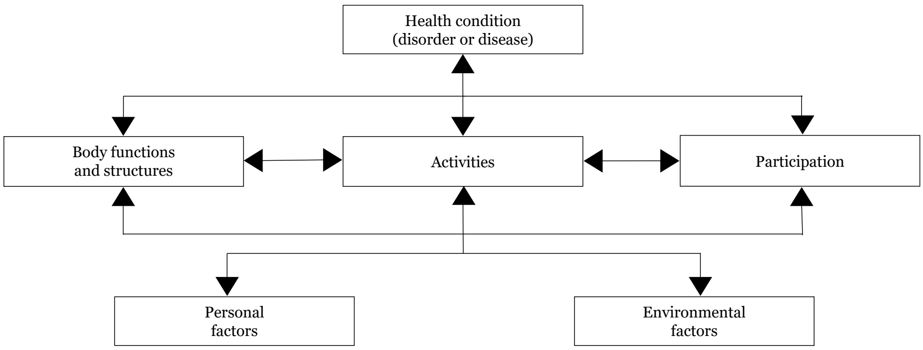

Figure 1. Interactions between the components of ICF based on the WHO [1].

The physical capacity of agility forms the resources for physical functioning that are needed to move safely from place to place and to perform other activities of daily living independently. There are no data with which to define determinants of agility for developing reliable measurement methods to evaluate agility and skill-related exercise programs to improve or maintain capacity of agility among untrained adults or older people. It has been found that the decline in agility begins in early midlife [28, 29], so ageing research needs various types of knowledge about physiological mechanisms associated with agility among adult people. Thus, the primary aims of this study were to examine test-retest reliability of the Agility Test for Adults (ATA) and to assess determinants of agility capacity.

2 REVIEW OF THE LITERATURE

2.1 PHYSICAL FUNCTIONING

2.1.1 Definition of physical functioning

The International Classification of Functioning and Disability (ICIDH-2) published in 1999 would be a suitable classification for all domains of functioning associated with both physical and mental health conditions [30]. After testing and assessing processes this classification was renamed the International Classification of Functioning, Disability and Health (ICF) in May 2001 [1].

According to the biopsychosocial model of ICF, functioning encompasses an individual's health condition, all body functions and structures, activities and participation that interact with personal and environmental factors [1]. Functioning is a positive aspect consisting of functional resources and an umbrella term for the before mentioned domains, whereas disability involves the interaction between a health condition, a decrease in body function, structure, capacity or participation, and the negative aspects of an environment [1].

Physical functioning is not only the absence of disability. The level of physical functioning of a person can be described in terms of capacity and/or performance to carry out daily functional tasks or activities. Physical functioning also includes changes in body functions and/or structures arising from physical functioning. The impact of the physical functioning level on a person's life can be understood by assessing body function as physiological function of the body, and body structure as anatomical parts of the body, but this level alone cannot provide information on whether the improvements are related to progress in physical function [31].

The assessment of physical functioning also includes components of activities and participation. An individual's status of physical functioning can only be understood in the full context of their health condition, personal and environmental factors. The purpose of the assessment of physical functioning is to understand a person's experience of possible disability in relation to impairments and/or in relation to interaction with personal and environmental factors [1, 32].

2.1.2 ICF-based description

The ICF provides a conceptual framework and a profound classification with common terminology to comprehensively delineate functioning across health conditions within the general population. In this context, an individual's functioning in a specific domain is a bidirectional and dynamic interaction of multiple relationships between health conditions and environmental and personal factors. These interactions are specific and not always in a predictable one-to-one relationship [1]. The present study focuses on describing the level of physical functioning in the ICF context [1] as shown in Figure 2.

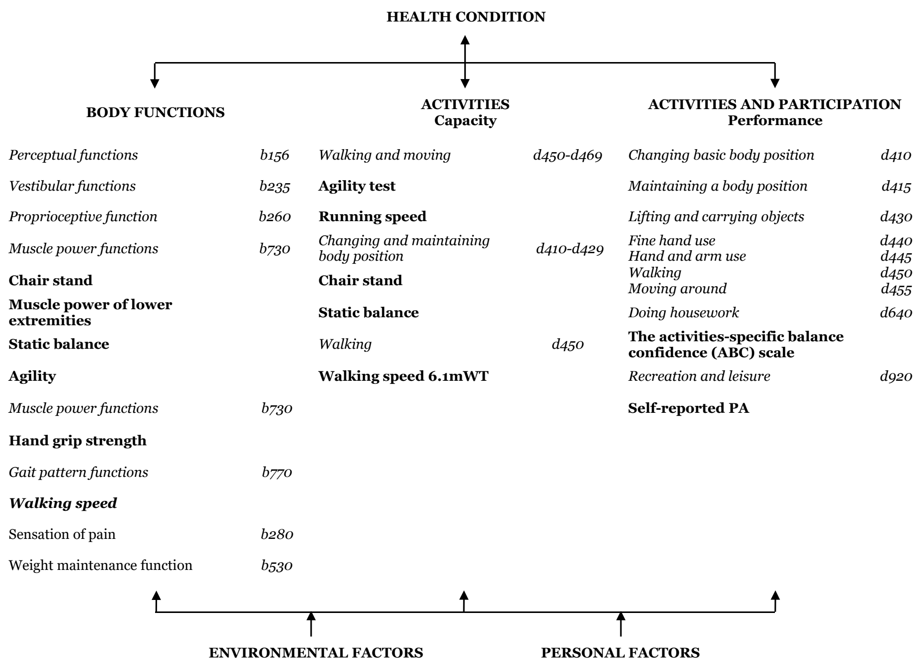

Figure 2. Structure and codes of the ICF as applied in the current study modified according to WHO [1].

2.2 AGILITY

2.2.1 Definition of agility

Sixty years ago, agility was defined as the speed in changing body direction or in changing body position through space i.e., as an ability to specify the movements to be accurate and rapid [33]. Ten years later, Hilsendager et al. [34] recognised that agility contains a variety of interrelated characteristics that constituted of physiological, biomechanical and advanced cognitive components. The broad definition as “the efficiency of movement throughout the entire kinetic chain regardless of the skill being executed” was put forward by Giles [35]. More specifically according to Chelladurai [36] and to Sheppard and Young [37], agility is a rapid and accurate movement of the whole-body in response to a perceived stimulus with the changes of direction speed (CODS). Many authors have suggested that CODS in movement is dependent on physical functions such as speed, strength and power, but does not include cognitive functions [11, 38-41]. Some studies have defined agility as the ability to change direction and speed of movement quickly and accurately [42, 43]. Nowadays it has been suggested that agility and CODS are different motor skills due to the unpredictability, and cognitive functions which are not included in CODS skills but included in capacity of agility [11, 39]. Liefeith et al. [44] suggested that capacity of agility should be described as movement solutions which demand the dynamic integration of speed, mobility, forceful contraction of muscles, balance and coordination, perceptual awareness and decision making to satisfy the demands arisen by a rapidly changing physical task. Different definitions of agility show that agility is a versatile skill consisting of a variety of physiological and cognitive functions. Unfortunately, there is no universally accepted definition of agility. The differences seen in how agility is defined may simply be due to a variety of factors, including the researcher’s professional perspective, expertise, or background within the wide variety of sub-disciplines within the area of sports science and human motion science.

2.2.2 Determinants of agility

The proposed models of agility form the basis for most definitions of agility. The first model consisting of two main functions, perceptual and decision-making functions and CODS function, has been published by Young and Montgomery in 2002 (Figure 3) [37, 38, 43]. Several studies measuring the capacity of agility or the effect of training on it have been executed by using athletes as participants and preplanned CODS movements around cones and poles to measure the capacity of agility [45, 46]. This type of test has been interpreted to evaluate agility capacity restrictedly, by only evaluating running and turning speed, or in a few studies also the ability to change directions quickly according to a marked track [36, 38, 47].

There are a few studies evaluating the relationship between sprint function and CODS, and between CODS and agility. In these studies, sprint function showed a stronger relationship with CODS than with agility [11, 40, 48]. Based on the point of view above, a new model (Figure 4) of agility for sport was proposed by Young et al. [39]. This model consists of the main determinants of agility. The difference between a previously presented model (Figure 3) and this new model is that CODS function was excluded. Most testing of athletes and research concerned with agility involved change-of-direction movements around obstacles such as cones and poles. Such functions are described as COD speed rather than agility [37, 39, 49–51].

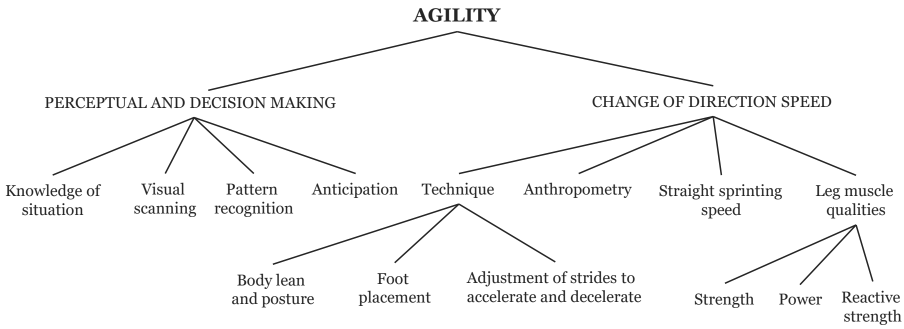

Figure 3. Model of main determinants of agility according to Young and Montgomery [38].

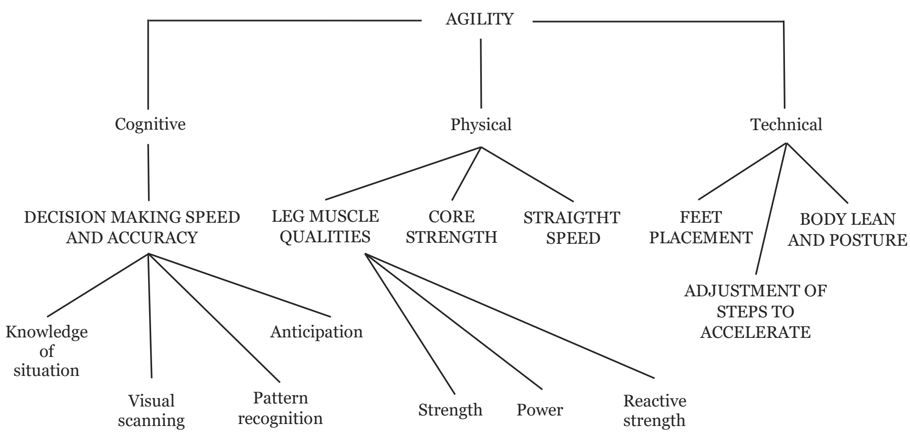

Figure 4. Model of main determinants on the capacity of agility according to Young et al. [39].

Jeffreys [42] has presented a theoretical framework with which to analyse agility and to focus on potential determinants that could limit the capacity of agility. This model (Figure 5) outlines perceptual, cognitive, physical, and motor control limitations and how these interact to affect movement. The aim of the task and the instructions to execute function are key task-related limitations that must be accounted for. Various gauges need to be acknowledged when considering the task limitations because these will affect the patterns of movement. According to Jeffreys, several determinants can be considered as environmental limitations, e.g. the surface, dimensions of movements or temperature [42].

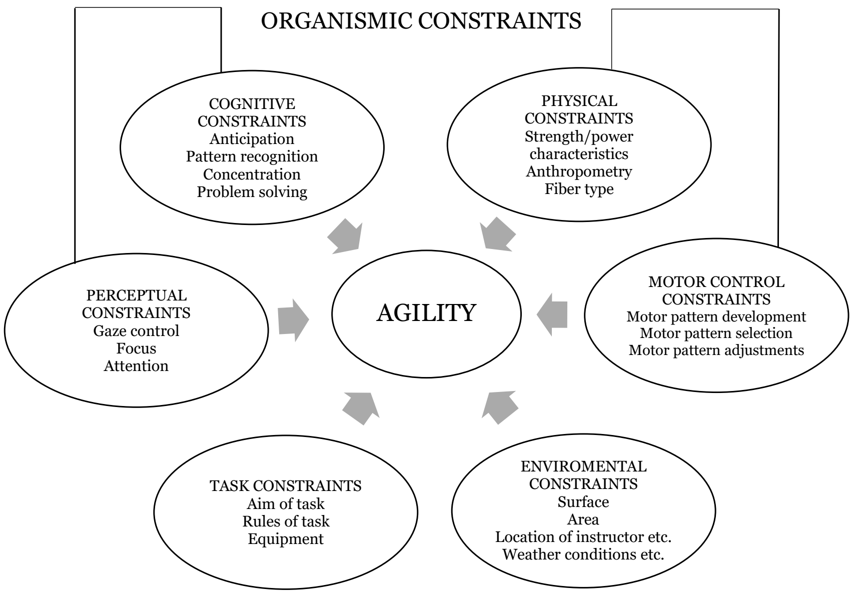

Figure 5. Constraints-based model of agility according to Jeffreys [42].

The above-mentioned theoretical models of agility have been developed in sport-specific context, but their content could be transferred to physical activities in real life. The ATA test has been developed (Study I) to assess the capacity of agility more comprehensively than the previously developed agility tests do among adults and older people. In this study, the main physical qualities defining the capacity of agility were partly modified according to previous models (Study I, Figure 2). These physical qualities, personal factors, content of task and factors of environment form the theoretical framework, which gives meaningful interpretation for neuromuscular and movement-related functions, mobility, and activities according to the ICF classification.

There are few studies indicating the relationships between agility, balance, strength or power among untrained or physically active adults or elderly people.

Most studies have been carried out on young athletes. Strong correlation coefficients between agility and a single physical function have not been reported in the literature. Trivial to moderate relationships have been found (r = -0.28 to 0.35) between agility and physical functions (10-m speed and power of lower extremities) [11], between agility and various unilateral jumps, [7] and 10-m sprint speed [40, 52] or between agility and balance [10, 53] among young male athletes. The number of participants ranged from 24 to 106 persons in the above-mentioned studies. Markovic [8] has shown low correlation coefficients between agility and squat jumping height (r = -0.15 to -0.35) and standing long jump (r = -0.12 to -0.27) in physically active men (n = 76). Among young female athletes, a weak relationship has been reported between agility and countermovement jumping height (r = -0.20; n = 12) [54] and squat jump (r = -0.31; n = 31) [10].

Significant correlation coefficients (r = -0.32 to r = -0.44) have been reported between agility and cognitive function tests [55] among elderly women and men (n = 164). Furthermore, high correlations (r = 0.77, r = 0.58 and r = 0.33) have been reported between execution time of agility, time of decision-making function and response time [56, 57] in young athletes (n = 31 and n = 12, respectively). Young et al. have shown that cognitive function explained 59% of the variance associated with execution of agility among football players (n = 31) [56].

2.2.3 Measurement methods

In fact, most tests purported to evaluate the capacity of agility are tests for CODS [36]. Comprehensive agility testing is difficult due to the multiple functions required for capacity of agility. The goal of the literature review has been to identify the most comprehensive tests of agility.

In clinical studies, capacity of agility has been evaluated using various stepping tests with samples of generalised population consisting of young and untrained adults, as well as elderly participants [28, 58-64]. These tests were developed to assess a participant's ability to take a quick step in one direction on to the box usually in the frontal plane, or the ability to quickly change directions while lifting one foot off the ground. The test of choice stepping reaction time (CSRT), was developed to evaluate dynamic balance with cognitive function for elderly people [65]. The test-retest reliability for a 'low-tech' version of CSRT-M (ICC = 0.74) has been studied [66]. Hill et al. [64] have reported coefficient of reliability for the Step Test with stepping with one foot on, then off, a block as quickly as possible (ICC = 0.90). Good re-test reliability was shown for The Ten Step Test evaluating agility among elderly people [28]. The step tests most likely require similar functions as the agility tests. For this reason, the step tests could be considered appropriate tests of agility. Descriptions of studies evaluating relative reliability for stepping tests are shown in the table 1.

Tasks of side-stepping agility were the most common measurement methods of agility capacity represented throughout published scientific articles [34, 38, 40, 41, 52, 67-69]. The side-stepping (or side hop) tests differ mainly in the changes of direction patterns. Some studies required a few changes of directions [34, 40, 41, 52], while others required a single change of direction during the tasks of side-stepping [40, 68]. The Edgren Side Step Test (ESST) was first introduced in the literature in 1932 by H.D. Edgren [70]. The ESST is a popular test of agility [37, 40, 71] and it evaluates an individual's mobility in lateral direction. Raya et al. [63] have shown the ICC values for test-retest reliability (ICC = 0.62), minimal detectable change (MDC = 3.91m) and standard error of measurement (SEM = 1.41) for the ESST [63]. Noyes et al. [72] developed 4 single-leg hop tests consisting of a single hop for distance, a triple hop for distance, a cross-over hop for distance and a 6-m hop for time that evaluate horizontal hopping functions. The test-retest reliability coefficients for each of the single horizontal hop tests were high (ICC > 0.91) among young, physically active men [73]. The Functional Ability Test (FAT) was developed by Itoh et al. [74]. The FAT consists of four tests (the figure-of-eight hop, the up-down hop, the side-to-side hop, and the hexagon hop) which are described as combination of highly demanding sports-specific movements of lower extremities [69]. In the nonathletic group, the intraclass correlation coefficients ranged from 0.76 to 0.92 and from 0.48 to 0.85 in the athlete group, respectively. Correspondingly, SEM values varied from 0.72 to 0.96 and from 0.47 to 1.43, respectively [69]. Worst et al. [75] evaluated test-retest reliability of the Change of Lateral Direction Test (COLD) with Pearson's correlation coefficients. There was a strong association between test session 1 and test session 2 (r = 0.88). MDC_{95} of the COLD ranged from 2.1 steps to 2.3 steps. This test only assesses movements in the frontal plane. The side-stepping tests are summarized in the table 1.

Table 1. Description of studies evaluating reliability or minimal detectable change (MDC_{95}) for stepping, side-stepping, agility and mobility tests.

Stepping tests/ Study	Test (Reference)	n	Gender (w, m)	Time interval	Relative reliability	Absolute reliability	MDC_{95}
Hill et. al (1996)	The Step Test (s) (Hill (1996)	14	Elderly participants	same day	ICC > 0.90		
Medell and Alexander (2000) Cho et. al. (2004)	The Rapid Step Test (s) (Medell and Alexander 2000)	34 62	Women of different ages Elderly participants	one week same day	ICC = 0.91 ICC = 0.42		
Delbaere et. al. (2016)	The Choice Stepping Reaction Time Test (s) (Lord 2001)	18 12	Older women Older men	between 2 days	ICC = 0.74		
Whitney et al. (2007)	The Four Square Step Test (s) (Dite and Temple 2002)	17 15	Older women Older men	same day	ICC = 0.93		
Miyamoto et al. (2008)	The Ten Step Test (s) (Miyamoto 2008)	20	Adult	same day one week	ICC = 0.96 ICC = 0.86		
Side-stepping tests/ Study	Test (Reference)	n	Gender (w, m)	Time interval	Relative reliability	Absolute reliability	MDC_{95}
Raya et al. (2013)	Edgren Side Step Test (m) (Edgren 1932)	97	Physically active men	between 2 days	ICC = 0.62	SEM = 1.41	3.91
Bolgla and Keskula (1997) Munro and Herrington (2010) Ross et al. (2002)	The 4 Single-leg Horizontal Hop tests (cm, s) (Noyes 1991)	20 11 11 18	Young participants Athletic women Athletic men Physically active men	between 2 days one week one week between 4 weeks	ICC = 0.95–0.96, 0.66 ICC = 0.80–0.87, 0.84 ICC = 0.80–0.92, 0.60 ICC > 0.91	SEM = 4.56–15.95, 0.13 SEM = 7.93–23.18, 0.08 SEM = 7.87–21.16, 0.08 SEM = 4.61–17.74, 0.06	 21.98–54.69, 0.21 21.81–58.65, 0.23
Ortiz et al. (2005)	The Functional Ability Tests (s) (Itoh 1989)	25 25	Athletic women Nonathletic women	between 2 weeks	ICC = 0.48–0.85 ICC = 0.76–0.92	SEM = 0.47–1.43 SEM = 0.72–0.96	
Worst et al. (2019)	The Change of Lateral Direction Test (number of steps) (Worst 2019)	51	Physically active young participants	one week	r = 0.88 between session 1 and session 2		2.1-2.3
Agility tests/ Study	Test (Reference)	n	Gender (w, m)	Time interval	Relative reliability	Absolute reliability	MDC_{95}
Hachana et al. (2013) Stewart et al. (2014) Raya et al. (2013	The Illinois Agility Test (s) (Cureton 1942)	89 20 24 97	Athletic men Athletic women Athletic men Physically active men	between 2 days between 3 days between 3 days between 2 days	ICC = 0.96 ICC = 0.83 ICC = 0.80 ICC = 0.68	SEM = 0.19 SEM = 0.30 SEM = 0.55 SEM = 0.65	0.52 1.80
Stewart et al. (2014)	The 505 Agility Test (s) (Draper and Lancaster 1985)	20 24	Athletic women Athletic men		ICC = 0.81 ICC = 0.77	SEM = 0.05 SEM = 0.07	
Pauole et al. (2000) Munro and Herrington (2010) Stewart et al. (2014)	T-test (s) (Semenick 1990)	304 11 11 20 24	Athletic and nonathletic participants Athletic women Athletic men Athletic women Athletic men	same day one week one week between 3 days between 3 days	ICC = 0.94-0.98 ICC = 0.96 ICC = 0.82 ICC = 0.83 ICC = 0.86	SEM = 0.17 SEM = 0.21 SEM = 0.23 SEM = 0.23	 0.48 0.58
Pauole et al. (2000) Beekhuizen et al. (2009)	The Hexagon Agility Test (s) (Roetert 1992)	304 26	Athletic and nonathletic participants Sedentary/ Physical active people	same day between 2 days	ICC = 0.86–0.95 ICC = 0.92		1.02
Vartiainen et. al (2006) Suni et al. (2014)	The Running in a Figure-of-Eight (s) (Daniel et al. 1982)	35 49	Young men Middle-aged participants	between 2 days one week	ICC = 0.87	Typical error = 0.14 Typical error = 0.26	
Mobility tests/ Study	Test (Reference)	n	Gender (w, m)	Time interval	Relative reliability	Absolute reliability	MDC_{95}
Rikli and Jones (1999)	The 8-foot Up-and-Go (s) (Rikli and Jones 1999)	42 34	Older women Older men	between 2–5 days	R = 0.90 R = 0.98		

More than 70 years ago, Cureton [76] introduced the Illinois Agility test (IAT) as a test for motor skills, particularly the function of running and swerving in healthy individuals. Few studies have described the IAT as a measure of multidirectional agility for a variety of sports [77–79] and have shown moderate to good test-retest reliability (ICC = 0.68–0.96) [63, 80]. Draper and Lancaster [81] developed the 505 test. They showed that this test was the most valid test for capacity of agility because of strong association with 20-metre sprinting speed. The developers of the 505 test also concluded that the velocity of the participant is not important in agility, but the capacity to alter this velocity quickly when the direction of movement changes is [81]. The Agility T-test is commonly used to evaluate changes of direction ranging from 90° to 180° including acceleration, deceleration, and lateral movements [82]. The intraclass correlation coefficients ranged from 0.82 to 0.98 for T-test among athletic and nonathletic participants [83-85]. It has been demonstrated that the T-test is a more valid measure of straight-line running speed than capacity of agility [83]. Nevertheless, Cronin et al. [86] reported the validity of T-test as a measurement method of agility for sport. Only one study has reported values of MDC_{95} for T-test among athletic women (MDC_{95} = 0.48s) and men (MDC_{95} = 0.58s) [84]. The Hexagon agility test has been described to involve functions of balance and coordination while moving the feet quickly around a hexagon from the centre to each of the six sides [87]. Pauole et al. [83] questioned the validity of the Hexagon test to assess agility. The ICC coefficients varied from 0.86 to 0.92 for the Hexagon test [83, 88]. Beekhuizen et al. [88] have shown MDC_{95} to be 1.02s for the Hexagon test. The Figure-of-Eight running test (FIG8) has been described as a test for measuring knee function [89, 90]. This test has also been used to measure capacity of agility in young healthy men [91–93], among postmenopausal women [94] and in middle-aged women and men [95], to evaluate dynamic balance among middle-aged female participants [96] and function of CODS in young male athletes [51]. ICC value was shown to be 0.87 and typical error was 0.14s in healthy men [92] and 0.26s in middle-aged participants [95] for FIG8 test. Nowadays, FIG8, T-test, IAT and 505 tests has been classified into CODS tests [51, 97]. The above-mentioned tests of agility are presented in the table 1.

Some tests of mobility (Table 1) have been used to measure the capacity of agility among elderly people. The Timed Up-and-Go (TUG) has been developed for the evaluation of mobility and balance among frail elderly persons [98, 99]. The modified version of TUG [100], the 8-feet Up-and-Go Test (UG) developed and validated by Rikli and Jones [101] has been used for evaluating agility and dynamic balance among older adults in many studies [101–106]. They found that the intraclass reliability coefficients (R) were from 0.90 in women to 0.98 in men for UG. This test is a part of the Senior Fitness Test protocol (SFT) [101].

2.3 MUSCLE STRENGTH

2.3.1 Definition of muscle strength

Human movement is produced by muscles that generate torque around the joints. The main function of muscle is to transform energy into mechanical energy to generate power and force, to produce movement and to maintain posture [107]. Muscle strength is defined as the amount of force that a muscle can produce in a specified movement and at a specified velocity of movement. Muscle power (explosive muscle strength) is understood as product of force and velocity [108] and it can be defined as the contraction rate of force development exerted within the early phase of rising muscle force [109]. In term of human physics, power reflects a muscle's function to do work and it is thus the rate of transfer energy [110]. In a range of physical activities including movements of power type, the time allowed to generate force is very limited (~ 50–250ms). The maximal voluntary contraction generated at a specific velocity is defined by the one repetition maximum (1RM). This is the maximal amount of weight that can be lifted once throughout the full range of motion of a joint [107, 111]. The longer time is needed to reach maximum force in most human muscles, i.e., ≥ 300ms for the knee extensors [112] than is needed to generate explosive muscle strength. The contraction rate of force development seems to be better related to most executions of both functional daily tasks and sport-specific functions compared to the maximal voluntary contraction [113]. A performance of daily activities requires both strength and power.

In the early 1700s, it has been shown that muscle strength was comparable to the number of associated muscle fibres [114]. Peoples' capacities to execute anaerobic or aerobic exercise vary according to their muscle fibre composition. After all, skeletal muscle is not composed of homogeneous groups of fibres with similar contractile properties and metabolic profile. Muscle fibres were classified into two main fibre types as slow-twitch (ST) and fast-twitch (FT) [115]. Later, researchers showed that FT fibres could be further divided into two groups with specific or metabolic profile: either more aerobic (type FT_a) or more anaerobic (type FT_b) fibre types [116]. This diversity of physiological properties of the various fibre types allows the execution of muscles in functions with various metabolic and mechanical demands [107]. ST fibres dominate the deeper parts of the muscle and FT fibres have functions on the superficial muscle [117]. In practice, fatigue-resistant ST or type I-fibres fire more slowly and works maintaining posture whereas fatigue-sensitive FT or type II-fibres fire more quickly and work controlling more explosive movements [118].

2.3.2 Determinants of muscle strength

Muscle force is related to the following mechanical and dynamic properties of the musculoskeletal system: cross-sectional area (CSA) [19, 119, 120], electromyography (EMG) activity [121, 122] and contraction time [123], velocity of movement [107, 124], length of muscle [107, 125, 126] or activation of sarcomere [107], joint angle [107], compliance of skeletal muscle [127] and joint [128].

Over a 100 years ago, Blix [125] proposed a mechanism of force production that depends on muscle length. He showed that muscle generates less force in a shortened or lengthened state than in a middle state. A muscle can generate the greatest amount of force when the number of cross-bridges between actin and myosin filaments is greatest at the middle lengths of the sarcomeres [107, 125, 126]. The factors responsible for this force-length–relationship include not only the length of sarcomeres, but also the number of cross-bridges. The force generated by muscle creates a moment with the joint because muscle is attached to bone. Muscle crosses one or more joints with which they function to produce movement [126]. The force-length-relationship means that the performance of daily activities relies on the angle of the joint for example carrying a heavy load with the elbows at 90° of flexion [107]. The magnitude of muscle force depends also on the velocity of movement (force-velocity curve). During eccentric function of muscle, an increase in velocity of movement results in higher force, whereas during concentric function of muscle it produces lower force. In summary, physiological cross-sectional area of muscle and length of muscle fibre are the main determinants of the length-force and the force-velocity relationships. The maximum force generated by a muscle is in relation to the number of sarcomeres activated synchronously with maximum shortening velocity and to the number of sarcomeres in series [129, 130].

2.3.3 Changes in muscle strength associated with ageing

The influence of muscle strength on human functioning can be examined by assessing the effect of individual, anatomical, physiological, and environmental factors on muscle strength. Decrease in muscle strength is dependent upon several factors including sex, age, muscle mass, type of muscle contraction, level of physical activity or presence of chronic diseases [131–137]. Human neuromuscular function changes according to the ageing process as shown in Figure 6.

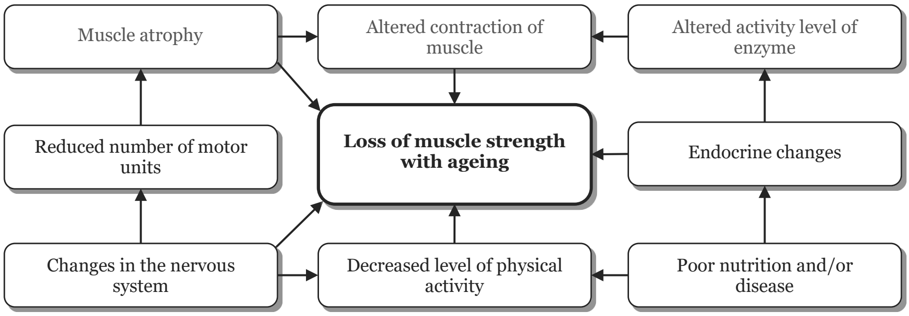

Figure 6. Multiple factors that lead to the loss of muscle strength in human ageing process [134, 135].

A change in the cross-sectional area (CSA) of human muscle fibre and a loss or an atrophy in the size and/or number of fibres, especially of fast-twitch fibres (type II) [134, 138], contribute to the decreased muscle mass and deteriorated neural activation associated with the ageing process [134, 139, 140]. In other words, sarcopenia, the loss of muscle mass associated to a loss of muscle power and strength [141-143] and shortening velocity [144] occurs also in healthy ageing [145]. Nowadays, it has been suggested that the annual decrease in muscle strength (dynapenia) would be many times greater than the loss of muscle mass or size due to neurological and non-muscle mass related functions in the decline of age-related muscle strength [140, 146]. Manini and Clark [147] proposed that these conditions, sarcopenia and dynapenia, need to be defined independent of each other because the age-related loss of muscle strength is partially explained by the reduction in muscle mass.

Age-related loss of skeletal muscle mass and changes in structural factors of the neuromuscular system lead to declined muscle function resulting in reduced power [148–151], reduced maximal strength [15, 150], slower contractile speed [135, 152, 153], decreased force steadiness [150] and increased variability of muscle contraction velocity and torque over repeat contractions [148, 150], and increased muscle fatigability [150, 154]. From a practical point of view, progressive and generalised loss of skeletal muscle mass (sarcopenia) and strength (dynapenia) lead to a general impairment of physical functioning and poor quality of life, and even to death in older adults.

Frontera et al. [131] have reported a loss of muscle strength of ~1%–1.5% per year after 60 years of age. The variability between individuals and the rate of decline in strength is greater among those with chronic diseases [137], higher age [131, 137, 155] and with less physical activity [103, 136, 156, 157]. The greater decline in isometric strength in the muscles of lower extremities than in those of upper limbs also causes variability in strength between muscles [131, 158, 159]. Age-related decline in maximal torque for the knee extensor muscles is larger for fast speeds of shortening contractions than for slower speeds [148]. It has been found that maximum contraction velocities of various muscles can be ~30%–40% lower in healthy older adults than in young individuals [160, 161].

Age related loss of muscle power in the product of force and velocity of muscle contraction is greater than that in isometric strength among elderly people [108, 162], and after the age of 30 years amounts up to 2% to 4% per year [131, 163, 164]. Especially the muscle power of lower extremities has been assessed as an important predictor of limitations for functional performance tasks such as rising from a chair, stair climbing and walking speed [15, 16, 108]. It has been reported that people with low muscle power have a 2–3 times risk of mobility limitations compared to those with low muscle strength [16]. Power is reduced by 10%–35% in older adults [131, 149, 165]. The loss of muscle power production may not be caused by a reduction in muscle CSA as much as by declined voluntary neuromuscular activation with advancing age [19, 146, 149, 151, 166].

2.3.4 Gender differences in muscle composition and strength during ageing

Structure, function and metabolism of muscle tissue change with age. Age-related changes in muscle composition are influenced by sex hormones, and thus observed changes differ between women and men [167]. Muscle groups of the lower extremities are ~50% stronger in men than in women [20, 168, 169], women have 25% smaller CSA, smaller type II-fibre areas for extensor muscles of the knee than men have [19, 131, 169], and muscle-articular stiffness and muscle stiffness are lower in healthy women compared with men [133]. However, age-related decrease in total appendicular skeletal muscle mass is shown to be larger in men (14.8%) than in women (10.8%) [170]. Age-related decline of skeletal muscle strength is associated with increased risk for functional limitations and decline of mobility in both men and women [171–173], but the rate of decline in muscle strength is shown to be faster in men [171, 174] while women may show earlier decline in strength [175] which is partly explained by the timing of menopause [176, 177].

2.3.5 Measurement methods

The ability of the muscle to generate force can be measured in several ways. There are methodological differences that must be acknowledged for measuring either static or dynamic function of muscle strength. Maximum muscle force has usually been measured using various kinds of dynamometers. Hand-held dynamometry (HHD) [178] is a simple, inexpensive and useful method to use during clinical research of the neuromuscular function. It was designed to measure isometric force. As the researcher holds the dynamometer against the area of the limb to be measured, the participant is asked to pull or push maximally for several seconds against the device. The force is defined in Newtons (N), or in kilograms (kg) [179]. The use of HHD has been described for various muscle functions [180–182]. Use of a belt to stabilize the HHD can improve the reliability of measurement for function of knee extension. ICC coefficients have been reported in the range of 0.88–0.90 [183] and 0.87–0.92 [184] for function of knee extension when belt-stabilization was used. Isometric strength testing of maximal voluntary contraction is usually measured as the force applied to the ankle with the participant seated in an adjustable straight-backed chair with the lower leg dependent and the knee flexed to 90°. The pelvis is secured by an adjustable belt [185]. The weakness of this method is that the strength generated by the muscle can be measured only at one joint angle during one session of measurement at a time compared to the isokinetic measurement method. Normative reference values are available for function of knee extension for healthy older adults [186].

A method of an isokinetic [187] measure is the most commonly used in the measuring of dynamic strength, for example, function of knee extension or knee flexion [148, 188, 189]. The requirement of the isokinetic strength measurement is that the body segment velocity of muscle shortening is set to a constant during maximum voluntary contraction [190, 191]. The isokinetic method evaluates the strength of the muscle on the whole movement with different speed, and the muscle strength can be recorded either in concentric or eccentric contraction regimens [190–192]. In particular, the evaluation of eccentric contraction requires standard isokinetic equipment because it allows controlled mechanical conditions for contractions of the measured muscles. Some measurements of strength have also included rate of force development that is the ability of the measured muscles to generate the force or torque in the shortest time [193–196]. It is possible to measure both isometric and isokinetic muscle strength as concentric torque at various angular velocities with modern isokinetic dynamometers [189, 197]. An isokinetic method is safe in clinical use [191, 198] and is feasible also in frail older people [199, 200]. The use of this method is limited by the need for special, expensive devices which are not portable [142]. Furthermore, disadvantages of isokinetic measurements include the fact that isokinetic movement seldom occurs in physical tasks of real life [190, 201]. The intraclass correlation coefficients of the isokinetic variables have been reported from 0.81 to 0.99 indicating 'good' to 'very good' reliability [189, 202, 203].

The Sargent Jump Test (SJT), also known as the vertical jump (VJ) test, was developed by Sargent [204]. The VJ is the one of most used tasks to evaluate the function of lower extremities. According to Sargent, the participant stands away from the wall and jumps attempting to touch the wall at the highest point of the jump. The difference in distance between the standing reach height and the jump height is the score [204]. This method has been shown not to be a valid assessment of leg extensor muscle function or capacity of explosive force by using a yardstick device [205]. Furthermore, SJT overestimates the jump height [206]. Nowadays, force platform [207, 208] are used extensively to measure force and power during a VJ as a squat (SJ) and countermovement jumps (CMJ) among various groups of participants [209–215]. The height for VJ is the difference between the height of the body mass center at the apex of the jump and its height when the participant stands in an upright position with heels on the ground. The flight time of the jump is used for calculation of the height of the rise of the body center of gravity and flight time is transformed to centimeters as 9.81xfligth time^2/8. This method forms the basis for the calculation of mechanical power [216].

The execution of VJ can be evaluated from a standing position and using both single- and double-leg takeoffs. In the late 1800s, it was already reported that the jumping height increased if person could pre-stretch muscles of lower extremities before a vertical take-off compared to a take-off starting from semi-squatting position without pre-stretching [208]. A maximal vertical jump starts from a static preparatory position, called SJ, or with a countermovement called CMJ. SJ and CMJ, measured by means of a contact mat and a digital timer, were the most reliable (α = 0.97 and 0.98; ICC = 0.97 and 0.98, respectively) and valid field tests for the estimation of explosive power of the lower extremities in physically active men, and the correlation coefficient was 0.89 between SJ and CMJ [211]. In another study, ICC coefficient was 0.91 among older women [217]. The method of SJ is more acceptable than the method of CMJ regarding the accuracy of prediction because SJ is a standard type of jump without too much variation [215]. However, it has been reported that the application of the SJ and/or CMJ on a force plate is practical for evaluating muscle power of the lower extremities in older adults because this method is easy-to-administer, time efficient and cost effective [201] with good reproducibility [217–219].

Isometric hand grip measurement by using a hand dynamometer [220, 221] is a good, simple method to measure an individual's hand grip strength in clinical practice. There are comprehensive and research informed protocols for measuring hand grip strength suggested by Roberts et al. [222]. The Jamar hand dynamometer is the most widely cited in the literature [222, 223]. It has shown excellent concurrent validity (r = 0.9998) [224]. According to a review, the test-retest reliability of grip strength measures obtained by the dynamometry was good to excellent (ICC > 0.80) [225]. The accuracy of the four dynamometers measurements compared to known forces was excellent in elderly people (r > 0.96) [226]. Many study groups have assessed the hand grip strength among different populations [223] and developed normative data for hand grip strength among adults [227–230].

Physical functioning is a concept which includes physical capacity needed to execute activities of daily living independently and safely. Functional capacity of lower extremities may be quantitatively evaluated by walking speed with fixed distance [231–233] or the time it takes to rise from a chair [234, 235]. SFT battery [101] is usually used for evaluating functional capacity among people aged 60 to 90 years [100, 103, 105, 236, 237]. The following measurement methods are included in the SFT, e.g. 30-Second Chair Stand and Chair Sit-and-Reach which is used to evaluate function and strength of lower extremities. Normative scores for SFT battery have been determined among older adults [104]. The Short Physical Performance Battery (SPPB) [238, 239] consists of three mobility tasks: gait speed, balance and chair stands. Test-retest reliability for SPBB battery has been reported (ICC = 0.723) [240]. The simple clinical test of functional capacity such as SPBB can be recommended to screen nondisabled older adults [241].

The European Working Group on Sarcopenia in Older People (EWGSOP) listed a wide range of techniques to evaluate the muscle mass in clinical practice and in research [142]. Anthropometric measures of muscle mass are not recommended to be used clinically for the diagnosis of sarcopenia because these measures are vulnerable to errors [142]. Computed tomography (CT) [242] and magnetic resonance imaging (MRI) [243] have been used for evaluating muscle mass or lean body mass. These methods have been shown as gold standards for assessing muscle functions like those in research [142]. The diagnosis of sarcopenia can be defined e.g. by counting the skeletal muscle index using Dual-energy x-ray absorptiometry technique (DXA) [142, 244–247] with which the amount of total appendicular skeletal muscle mass is evaluated normalized by height squared [143, 248]. A skeletal muscle index, two standard deviations below the mean skeletal muscle index of young participants as reference groups, were determined as the cut-off points for sarcopenia by gender (7.26 kg/m^2 for men; 5.5 kg/m^2 for women) [248]. In the later studies, it has ended up in parallel cut-off points [143, 233]. Due to the need for special equipment, DXA is not an appropriate method in large scale epidemiological studies [249]. Bioimpedance analysis (BIA) is an inexpensive, easy to use and reproducible method to evaluate the volume of fat and lean body mass. Skeletal muscle mass index can be calculated as skeletal muscle mass/height^2 [249] or as absolute muscle mass/height^2 [250] by using BIA method.

2.4 PHYSICAL ACTIVITY

2.4.1 Definition of physical activity

Physical activity (PA) is defined as any bodily movement produced by contraction of skeletal muscles increasing energy expenditure [163, 251, 252]. Different subcategories of PA are leisure time physical activity (LTPA), commuting physical activity (CPA), miscellaneous home physical activities (MHPA), and occupational physical activity (OPA) [251-253]. Sleep is an important regulator of time available for PA although it includes relatively minimal movements [254], and sleep disturbance or deprivation can decrease daily physical activity [254, 255].

Physical activity and energy expenditure (EE) cannot be equated [256]. PA is behaviour or a movement that results in EE [252, 257, 258]. The energy expenditure reflects the energy cost or intensity associated with a given PA [252, 257], and EE also varies from person to person, depending on age, body mass, gender, and efficiency or manner of movement for physical activity [257, 258]. EE of physical activity is the most variable component of total energy expenditure (TEE) that can be estimated to be around 15%-30% of TEE [259]. Based on personal interests and needs, a person participates in LTPA during leisure time. LTPA includes activities that result in substantial EE, including time spent in household work, gardening, commuting and other transportation activities and the more commonly recognized exercises of running, swimming, bicycling and aerobics [252]. Exercise is considered a subcategory of LTPA, and it can be described as planned, structured, repetitive and purposive movements of body in order to improve or maintain one or more physical fitness components such as strength, agility, balance or flexibility [163, 251, 252, 260]. It is important to notice the disparity between physical activity and physical fitness on the intra-individual day-to-day variability: physical fitness will stay relatively static whereas physical activity will undeniably vary on daily function, taking time to change [259]. Sport is a subset of exercise, and a defined goal exists. It can be performed as a part of a team or individually [261].

2.4.2 Determinants of physical activity

The dose of physical activity is dependent on mode/type, intensity (physiological effort associated with participating in a special type of PA), frequency (number of events of PA during a specific time period), and duration (time of participation in a single bout of PA) of the activity [251]. The evaluation of physical activity level based on above-mentioned determinants has been widely used although they are estimated to be less accurate than measurement methods based on the energy expenditure [262].

The dose of LTPA can be expressed in terms of the volume (absolute intensity) or the quantity (relative intensity) of the energy expenditure over the course of the various time intervals [252]. Volume of physical activity is a product of the absolute intensity, frequency, and duration resulting in the total energy expenditure which can be described with the metabolic equivalent of task minutes (METmin) or MET hours (METh) (Intensity MET x duration x frequency of activity) [252]. Buskirk et al. [263] used the term activity metabolic index for calculation of the metabolic equivalent hours. One MET can be calculated by dividing the oxygen uptake in $ml \cdot kg^{-1} \cdot min^{-1}$ by 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ which is considered a resting metabolic rate obtained during quiet sitting (1.2 kcal/min for a 70-kg person) [252, 264]. For example, work at 2 METS requires 7.0 ml O_2/kg/min [264]. According to the Compendium of Physical Activities [265], walking on a firm surface at 4.0 km/h corresponds 3.0 MET [265, 266]. This conventional definition of MET has been reported to overestimate energy expenditure in obese and elderly persons [267, 268]. However, the standard MET values are recommended to use instead of the corrected MET values evaluating physical activity of the population but not individually [269]. MET values have the advantage of providing a common method to describe workload levels across all populations and most modalities [270].

Intensity of physical activity can also be described in terms of percentage of maximal oxygen uptake (VO_{2max}) evaluating the intensity of relative to the maximal physical capacity of an individual as the relative intensity of aerobic activity [252]. Converting the absolute data of physical activity into the relative intensity of PA is possible only with the person's value of maximal oxygen uptake or related dimension [271]. The gross values of the relative intensity including the resting metabolic rate, can be calculated with the equation ([absolute intensity of PA / VO_{2max}] · 100). When the relative intensity is expressed in net value, it can be calculated with the same equation after the subtraction of the resting metabolic rate ([absolute intensity of PA – resting metabolic rate] / (VO_{2max} – resting metabolic rate) · 100) [252]. Instead of maximum oxygen capacity other related dimensions, like heart rate, can be used as an expression of intensity.

2.4.3 Measurement methods

Over thirty years ago, more than thirty different measurement methods of physical activity had been identified [272]. By then, it was already recognized that the methods have their own weaknesses and strengths in terms of reliability, usability, validity or accuracy. Self-report methods are more practical, but their poor validity and sensitivity have been reported by researchers [258, 273-275]. The most objective measurement methods for evaluating energy expenditure as doubly labelled water (DLW), direct calorimetry and indirect calorimetry, were considered as "gold standards" for comparison with other methods. DLW and calorimetry are excellent indicators of energy expenditure, but the disadvantages of these methods are the high costs and special equipment, and they are inappropriate methods to evaluate behavioural function of physical activity. DLW do not give results of intensity variation [258]. Evaluating physical activity has difficulties because PA is multidimensional, and no single measurement method can assess all subcomponents and dimensions in the physical activity of interest [258].

Self-reported methods are popular and practical for evaluating PA because they are relatively inexpensive and easier to use and enable collection of PA data in large studies in a short time. A variety of formats for questionnaires of physical activity are available in the literature allowing persons to self-report their physical activity levels over a range of intervals. A daily diary or simple recall questionnaire of physical activity may provide an excellent screening method in practice although subjective methods have been estimated to be inaccurate to give a complete picture of an individual's physical activity. These methods include electronic or paper diaries and questionnaires as well as standardized interview techniques (face-to-face or by phone) [258, 259, 276]. Self-reported methods have numerous limitations which include difficulties in substantiating the intensity, duration and frequency of physical activity, mastering its all domains of that, the cognitive demands of recall and the social desirability bias [274]. As a result, these methods have a floor effect, in other words, the lowest score available is too high for inactive respondents and self-report measures are not able to sort out small differences in the level of physical activity [256, 277]. It has also been shown that high intensity activities are reported more accurately than low intensity activities [278]. Few studies have reported that the accuracy of self-reported PA (e.g., under- and overestimation) may be directly related to the levels of physical activity [279-281]. Questionnaires do not account for individual variations in weight, metabolic factors, and intensity of physical activity which all have an effect on the expended energy [282].It has been suggested that most questionnaires have restricted value to calculate energy expenditure of physical activity by ascribing MET values with accuracy [273, 283].

While metabolic rate is now more commonly evaluated indirectly from measurement method of the oxygen consumed, heat energy produced by the body can be accurately measured with direct calorimetry [284]. The rate of heat production in an individual is directly proportional to EE [284]. The Atwater-Rosa calorimeter, also often called a respiration calorimeter, was the first one device [285, 286] measuring whole-body heat loss and oxygen consumption in humans [284]. Calorimetric methods are particularly useful for evaluating energy expenditure for specific physical activities over short intervals in controlled conditions. They are impractical methods to use in free-living conditions or in large populations due to expensive specialized equipment and their complex use [258, 287].

Indirect calorimetry is the most widely used measurement method to evaluate the rate of energy production [284] because of its usefulness evaluating basal metabolic rate, resting and total daily energy expenditure, thermic effect of food and energy expenditure of specific activities [287]. This method evaluates the difference in oxygen and carbon dioxide contents between inspired and expired air allowing the determination of oxygen consumption and carbon dioxide production [284]. The doubly labelled water [288] is a method of the indirect calorimeter that was used in the first validation study in humans in 1982 [289]. The DLW method involves introducing stable isotopes of both hydrogen and oxygen (usually orally taken) into the body water. Evaluating the rate of loss of these isotopes, estimates

CO_2 production which can be used to measure energy expenditure [290]. Due to high cost of the isotopes and special equipment, there is limited usability of the DLW among a large population. Also, DLW does not differentiate the duration, frequency, or intensity of specific PA [257, 258, 276].

Owing to the high costs and special equipment of the direct calorimetry and of the DLW, device based methods such as heart rate monitoring and accelerometers have been proposed separately [291, 292] and in combination [293, 294] as more feasible and pragmatic alternatives in measuring TEE and EE of physical activity in free-living individuals. PA motion sensors that combine accelerometer with heart rate monitor have been suggested by many to offer a greater measurement validity of PA compared with either method used alone [294, 295]. It has been shown that the combined heart rate and motion sensor was less accurate for individual assessment for TEE and EE of physical activity but a valid method for estimating those variables in a group of healthy men [296] and a valid method for evaluating free-living EE of physical activity on group level in adults [295]. Validation of these types of motion sensors is under development.

2.4.4 Physical activity and physical functioning

Regular participation in PA is associated with positive health-related outcomes. PA choices and the physiological, psychosocial, and environmental determinants of PA participation vary by age, sex, and educational attainment [297]. Participation in physical activity delays the decline in mobility performance in midlife [4, 298–300] and with higher physical activity level in middle-age, people have better mobility and performance of lower extremity function at old age [2, 3]. Therefore, PA has a remarkable role in maintaining physical fitness because physical fitness denotes conceptually physical capacity that is needed to perform everyday activities and to cope with daily tasks and activities independently and safely [104]. Parsons et al. [301] have showed that regular PA may also contribute to better agility, coordination and balance function in elderly people. PA decreases and pattern of habitual physical activity change with increasing age [157, 302], especially the amount and intensity of PA or specific sport activities decreases and sedentary behaviour increases after the age of 40 years [303], and the biggest decrease in PA occurs when people are in their sixties [304]. Verbrugge et al. [305] have reported peak participation in PA at ages 30 to 49 years and lower participation reported in younger and older age groups. Any kind of PA is better than sedentary behaviour [103, 306]. Everyday physical activity such as housework, gardening and walking are associated with maintained functional independence in older people [307].

3 AIMS OF THE STUDY

General aims of this study were to evaluate the relative and absolute reliability and clinical usefulness of the Agility Test for Adults in physically inactive or active women and men, and in male former elite athletes and their controls, and to utilize ICF classification to describe the measures of physical functioning.

More specific aims of this study were:

1. To evaluate the test-retest reliability of the Agility Test for Adults and to determine minimal detectable change of the ATA in untrained women and men (Study I).

2. To evaluate the determinants of agility capacity in physically inactive and active women and men (Study II).

3. To determine the relationship between capacity of agility and selected objective and subjective measurement methods, and to evaluate the feasibility of the ATA among male former elite athletes and their controls (Study III).

4. To determine the level of mobility and muscle strength, as well as self-reported balance confidence, and to evaluate the effects of the participation in competitive sports in young adulthood or life-long leisure-time physical activity on the present level of physical functioning comparing male former elite endurance and power athletes with their controls (Study IV).

4 MATERIALS AND METHODS

This doctoral thesis consists of four cross-sectional sub-studies. The Ethical Committee of the Research and Development Centre of the Social Insurance Institution in Finland approved the study designs of the studies on healthy adult people (Studies I–II). The studies including a group of male former elite athletes (Studies III–IV) were approved by the Ethics Committee of the Hospital District of Helsinki and Uusimaa in Finland [308]. All participants gave their written informed consent prior to the study (Studies I–IV).

4.1 Participants and study design (Study I)

In this cross-sectional study, participants were recruited from a communal health care system, employees at a children's day care centre, and a few local companies during spring 2005. Altogether fifty-two women (n = 25) and men (n = 27), aged 28—55 years, were recruited. The eligible participants, who did not do regular sport activities, without diagnosed diabetes, serious musculoskeletal disorders of lower extremities, or neurological diseases, and without any medication that affected the function of their central nervous system, were included in the study. During the first test session, two men did not want to continue in the study because they were busy with their work, thus 50 out of 52 participants volunteered for the measurements. The personal factors of participants, who were eligible for the study I, are presented in the table 2.

The repeated measures design was used to examine the test-retest reliability of the agility test and to evaluate the feasibility of that. For the test-retest reliability, participants carried out three test sessions in a health centre department of physiotherapy during the week. Each participant was measured in the afternoon between noon and 4 p.m. and on the same day of the week by the same experienced physiotherapist. During the testing, all participants received identical instructions according to a detailed protocol. All measurements were executed barefooted in light clothes, a t-shirt and shorts. Participants were instructed to avoid vigorous exercise in the 24 hours before testing, to sleep enough the preceding night, and not to eat two hours before the test sessions. The physiotherapist demonstrated the test and participants practised once before starting the test. On the first day, the test of agility was executed three successive times. One week later, participants executed the first three tests to evaluate one-week test-retest reliability of the agility test. Thirty minutes later, the agility test was repeated three times for same-day test-retest reliability. All measures were video-recorded for checking the number of errors during the test.

4.2 Participants and study design (Study II)

In this cross-sectional study, 149 women (43.0 ± 7.3 years) and 84 men (44.0 ± 7.7 years) were recruited from the members of a local association of unemployed people, participants from occupational retraining courses, secondary schools, and from staff members of the local university and private companies. The recruiting information was the same for all. To be eligible for participation in the study, participants should not be engaged in regular sporting activities for at least three times a week or regular training for the past five years. Participants should be middle-aged and healthy. In addition to the medical examination, the participants answered a questionnaire in which symptoms and pain premises of lower extremities were surveyed. They had to cope with physical tests, and to complete all the required questionnaires. In total the results from 106 (71.1%) women and 66 (78.6%) men were valid and available. The distribution of personal factors among participants is shown in the table 2.

Before the measurements of physical functioning, all participants were examined by an experienced physician to be qualified to participate. Medical screening included cardiovascular, musculoskeletal, and neurological examinations. Brochures about the current study provided the information on the purpose, benefits, and risks of the study to the participants before they signed a written consent to participate in the study. The same physiotherapist explained to the participants what to do and demonstrated all the tests at the beginning of the test session. Instructions were identical. After instructions, the session of measurement started with a 15 min standardized program of warm-up including flexibility exercises, light jogging and stretches of muscle. Participants also carried out one training test for all tests.

4.3 Participants and study design (Studies III–IV)

The original study participants consisted of male former elite athletes who represented Finland between the years 1920 and 1965 in selected sports at least once in the Olympic Games, World or European championships or intercountry competitions [309]. A total of 2675 athletes fulfilled the inclusion criteria, and the full name, place and date of birth were traced for 2613 (97.7%) men. The following sports were selected: cross-country skiing, ice hockey, track and field athletics, basketball, boxing, shooting, soccer, weightlifting and wrestling. The controls (n = 1712) were selected from Finnish men who, at the age of 20 years, had been classified as healthy (military class A1) at the medical examination for induction into compulsory military service [309]. The controls were selected from public archives of the register of men liable for military service and matched for birth cohort and area of residence with the athletes. This procedure was carried out in the years 1978–1979, when 85.5% of athletes were identified, after which no more controls were included [309].

The athletes were classified as follows: endurance sports (cross-country skiing, long- and middle distance running), mixed sports (ice-hockey, basketball, soccer, track and field sports as decathletes, hurdles, jumpers and sprinters) and power sports (boxing, shot putting, track and field throwers, weight lifting and wrestling). The division was based on the ranking of the sports by the average maximal oxygen uptake for male athletes in the Swedish national team [310]. Basketball and ice-hockey players, shooters and weightlifters were not originally within the study population when the reference sample was chosen but were included afterwards.

In 1985, the participants (athletes n = 1518; controls n = 1010) responded to a questionnaire on physical activity, health and lifestyle [309]. Identical questions were used in the years 1995 and 2001. An epidemiological and clinical study was carried out in the year 2008. An invitation to participate in the clinical follow-up study was sent to all former elite athletes (n = 747) and their controls (n = 436) who were alive and who had answered at least one of the previous questionnaires sent in 1985, 1995 or 2001. Of the invited participants, 63.9% of the former elite athletes and 67.9% of the controls had died. In the year 2008 altogether 599 participants of which 392 former elite athletes and 207 controls (Figure 7) agreed to participate in the clinical study including a physical examination, laboratory tests, and questionnaires.

In the years 20082010, a subgroup was randomly selected from the 2008 cohort of former elite athletes and their controls. The subgroup consisted of 50 endurance athletes, 50 power athletes and 50 controls. Of these, 15 (30%) middle-, 24 (48%) long-distance runners and 11 (22%) cross-country skiers composed the endurance subgroup. The power sports group consisted of seven (14%) shot-putters, four (8%) discus throwers, two (4%) hammer throwers, four (8%) javelin throwers, 13 (26%) boxers, 17 (34%) wrestlers, and three (6%) weight lifters. The selection of the subgroup was done by using GMATCH macro [311]. Matching criteria to select controls were birth cohort and area of residence with the athletes.

In the studies III and IV, the participants were excluded if they were unable to complete the questionnaires and/or to execute the measurements of physical functioning. Of the 150 participants, six controls, six power athletes and two endurance athletes refused (9.3%) to participate in the second clinical test session for personal reasons. Altogether 34 (22.7%) participants were not able to execute the agility test due to declined function of lower extremities and various psychological and physiological reasons. Figure 7 shows a flowchart of study participants and their reasons for not completing the agility test. Overall data from 97 (64.7%) participants were available for regression analyses. Baseline personal factors of the participants who were included in the studies III and IV are shown in the table 2.

Table 2. Personal factors of participants (Studies I–IV).

	Study I		Study II		Studies III–IV		
Personal factors	**Women n = 25**	**Men n = 25**	**Women n = 149**	**Men n = 84**	**Endurance n = 50**	**Power n = 50**	**Control n = 50**
Age (years)	43.3 (6.6)	42.8 (7.2) 0.776	43.0 (7.3)	44.0 (7.7) 0.314	76.2 (5.2) 0.449	74.9 (5.1) 0.608	75.4 (5.0)
Height (cm)	165.0 (6.0)	179.9 (7.2) <0.001	164.6 (5.8)	179.1 (6.1) <0.001	173.7 (6.1) 0.708	173.5 (9.9) 0.896	173.3 (5.9)
Weight (kg)	64.7 (12.7)	82.0 (6.8) <0.001	66.3 (11.4)	87.6 (11.5) <0.001	75.3 (11.7) 0.289	84.8 (16.4) 0.015	77.8 (11.5)
Self-rated health (%)				**0.479**			**0.193**
Very good or good			33.0	26.3	12.0	8.2	4.0
Fairly good			44.4	46.3	60.0	51.0	46.0
Average or fairly poor					28.0	40.8	50.0
Fairly poor			22.2	27.5			
Self-rated fitness (%)				**0.891**			**0.403**
Very good or good					18.0	8.3	6.0
Fairly good			36.8	40.0	48.0	52.1	50.0
Average or fairly poor			46.5	43.8	34.0	39.6	44.0
Fairly poor			16.7	16.3			

Values are means (± SD) and percentages. *P*-values compared to women (Studies I–II) and to controls (Studies III–IV), *P*-values between the groups (Studies III–IV).

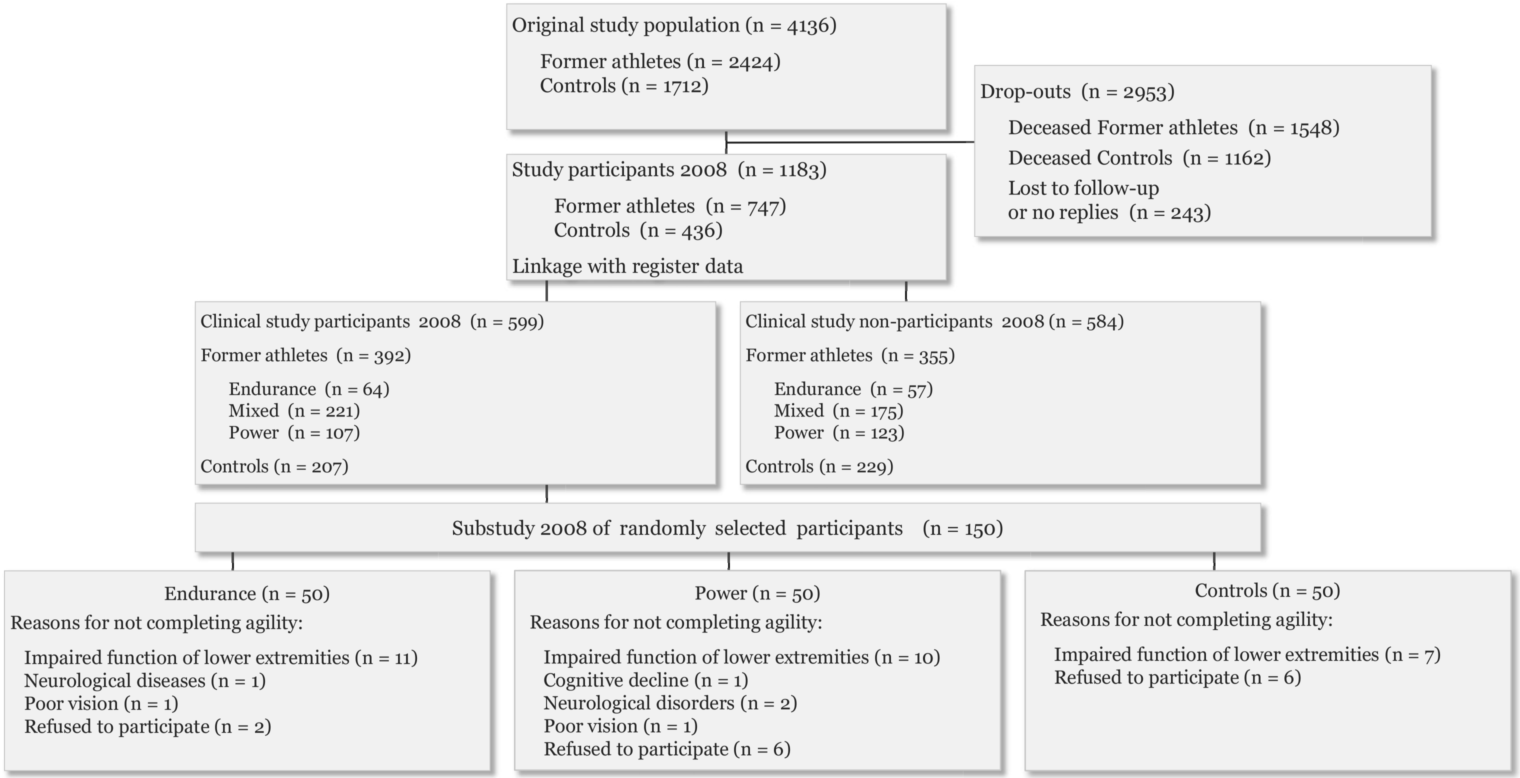

Figure 7. Participant flowchart through the study (Studies III–IV).

Each participant attended two assessment sessions over the period of August 2008 to January 2010. The test sessions of physical functioning including self-reported questionnaires were always carried out between noon and 4 p.m. The first test session of physical functioning comprised chair stand, handgrip strength, walking speed, and self-rated health and fitness questionnaires. On the second test session, participants executed agility, jumping height, static balance, and completed self-reported ABC-scale questionnaire. An experienced physiotherapist, who was blinded to the athletic history of the participant, used a detailed protocol including standardized instructions. All participants received identical instructions on measurements that were conducted barefooted in light clothes. After the instructions, the test session started with bicycle exercise for 3–5 minutes and a standardized battery of dynamic stretches. After the warm-up, the physiotherapist demonstrated the test and the participants could practice each test once. Breaks were allowed, both within and between measurements.

4.4 Measurements in the ICF domains (Studies I–IV)

Measurements of this study were classified into four components: body functions, activities (capacity) and participation (performance), and personal factors according to the ICF. The ATA test is described in the section 4.4.2.

4.4.1 Clinical measures of body functions

The domains measured were perceptual functions (b156), vestibular functions (b235), proprioceptive function (b260), muscle power functions (b730), coordination of voluntary movements (b7602), gait pattern functions (b770), weight maintenance functions (b530) and sensation of pain (b280) using the following eleven measurements (Figure 8) of which five are measurements of mobility and they have all been described in more detail in Chapter 4.4.2.

Vertical squat jump (VSJ) (Studies II–IV) and **countermovement jump (CMJ)** (Studies III–IV) tests were used to measure the explosive force of leg muscles [216]. The participant was barefooted. At the starting position for VSJ, the participant stood with their knees flexed at 100 degrees with their hands on their pelvis. At the starting position for CMJ, the participant stood keeping their body in a straight position with their hands on the pelvis. They could perform a quick countermovement with knees flexed to 90 degree before jumping and to jump as high as possible. The participant had three attempts in VSJ and in CMJ, with 1–3 minutes rest between the attempts. The flight time (s) was transformed to centimetres (cm) as $9.81 \times \text{flight time}^2/8$ by Bosco et al. (1983). The highest value of three jumps was used. Both jump tests were measured by

Activities and Participation (Performance)

Changing basic body position (d4103-d4106); Maintaining body position, other specified (d4158);Carrying, moving and handling objects (d4308);Fine hand use (d4400);Hand and arm use (d4452); Walking (d4500, d4502-4503); Moving around (d4551-4552); Doing housework (d6402)
• *The Activities-specific Balance Confidence (ABC) scale (%)*

Recreation and leisure (d920)
• *Self-reported short-term leisure time physical activity (LTPA)*

Body functions

Perceptual functions (b156); Vestibular functions (b235); Proprioceptive function (b260); Muscle power functions (b730);
• *Chair stand*
• *Countermovement jump (cm)*
• *Running speed*
• *Standing long jump (cm)*
• *Squat jump (cm)*
• *Static balance*
• *Agility Test* (Coordination of voluntary movement as eye foot coordination; b7602)
Muscle power functions (b730)
• *Hand grip strength (kg)*
Gait pattern functions (b770)
• *6.1mWT at full speed*
Weight maintenance functions (b530)
• *Body mass index (BMI) (kg/m²)*
Sensation of pain (b280)
• *Nordic musculoskeletal questionnaire*

Activities (capacity)

Acquiring complex skills (d1551); Making decisions (d177); Shifting the body's center of gravity (d4106); Maintaining body position, other specified (d4158); Jumping (d4553)
• *Agility Test for Adults: time (s) and error (number)*
Sitting (d4103); Shifting the body's center of gravity (d4106)
• *Chair stand (s)*
Maintaining body position, other specified (d4158)
• *Static balance (s)*
Acquiring complex skills (d1551); Shifting the body's center of gravity (d4106); Maintaining body position, other specified (d4158); Running (d4552)
• *20 m running speed (s)*
Walking short distances (d4500)
• *6.1mWT at full speed (m/s)*

Personal factors

Age; Height; Weight; Waist circumference; Fat percent; Lean body mass; Self-rated health and Self-rated fitness

Environmental factors

The research laboratory

Figure 8. The ICF as a reference framework, classification and code numbers for this study including measures of physical functioning (Studies I–IV) modified from the International Classification of Functioning, Disability and Health [1].

using a contact mat (Newtest Powertimer®, Newtest Oy, Finland). The coefficient of variation (CV) 3.9 % has been obtained between repeated measurements of vertical jumping height among former elite athletes aged 45 to 68 years [312]. Markovic et al. [211] have shown that SJ and particularly CMJ measured with a contact mat connected to a digital timer are the most reliable and valid tests for the estimation of explosive power of the lower extremities among all popular jumping tests. Additionally, CMJ has reported to be the most reliable test to evaluate power of lower extremities among athletes in different age groups [313] and in physically active older women [217].

The explosive force of leg muscles in horizontal direction was evaluated by using a reliable field test of **Standing Long Jump (SLJ)** test [211] (Study II). A participant jumped from a standing position, swinging arms and countermovement of lower extremities was permitted. For each test, the participant was instructed to jump as far as possible. Each participant performed three jumps separated by one to three minutes' rest. The longest result of SLJ was used for further analysis. SLJ had great reliability (ICC = 0.95 and α = 0.95) and within-subject variation was low (CV = 2.4%).

In 1954, Bechtol [220] demonstrated the dynamometer which is suitable for measurement of the compressive force of the hand and in which it was possible to adjust the scope of the hand grip according to the movement of the test and the size of the hand. **Hand grip strength** (Studies III–IV) was measured with the dominant hand, elbow flexed at 110° angle, the forearm pointed forward in a 45 degree angle, wrist in a neutral position, and the interphalangeal joint of the index finger at the 90° angle against to the handle [314]. The participants were instructed to grip the handle (Good Strength, IGS01, Metitur Oy, Jyväskylä, Finland) as hard as they could for 3–5 seconds. The second test was performed 30 seconds later. The best result of the dominant hand was used in the analysis. If the difference between the two measurements was greater than 10%, a third test was done 30 seconds later. Test-retest correlation coefficient of more than 0.95 has been shown for hand grip strength in older people aged 65–85 years [315].

Body mass index (BMI) (Studies I–IV) was calculated by dividing the body weight with height in meters squared (kg/m^2). For the analyses, BMI was categorized according to the WHO into underweight (< 18.50 kg/m^2), normal weight (18.50–24.99 kg/m^2), overweight (25.00–29.99 kg/m^2), and obesity (≥ 30.00 kg/m^2) [316].

The standardised **Nordic musculoskeletal questionnaire** [317] (Study II) was used to estimate musculoskeletal pain among participants that were enquired about the presence of lower back and lower extremities pain during the preceding six months and one week, respectively.

4.4.2 Clinical measures of activities (capacity)

The domains measured were acquiring complex skills (d1551), making decisions (d177), shifting the body's center of gravity (d4106), maintaining body position, other specified (d4158), jumping (d4553), sitting (d4103), walking short distances (d4500) and running (d4552), using the following five measures of mobility (Figure 8). *Mobility* is defined as getting into and out of body position and moving from one location to another like squatting and sitting, as maintaining a body position, and also as moving along a surface on foot, step by step, so that one foot is always on the ground, such as walking short and long distances, and moving around by jumping or running [1].

Agility Test for Adults (ATA) (Studies I–IV) has been designed and developed by the authors. The test track is 10.5 m long and includes 25 marks variously positioned on the left or the right side of the median line. The participant jumped with two feet whenever there was a square on either side of the median line. On a cross mark on the left side of the median line, the participant jumped with the left foot and on a cross mark on the right side of the median line, with the right foot. The participant stood behind the starting line and after getting permission he had to jump on all the twenty-five marks as fast as possible, and with minimal errors. Possible errors were counted (jumping with the wrong foot on a cross mark, or with one foot on a square, or the foot did not hit the mark). Execution times were measured in seconds with two decimals by using a stopwatch and errors during the test were checked for each trial from video recordings (Sony Digital Handycam. DCR-TRV 25 E). The best performance time of three ATA performances was used for analyses, except all three were used for reliability coefficients. The effect of error in the execution time of ATA has been previously analysed with a bigger data (unpublished). Every error increased the execution time of ATA by 1%. The current study has shown that ATA is reliable and stable among the studied group of untrained women and men.

Chair stand test (Studies III–IV) is widely applied in measurements of mobility in older people [238]. The participant is asked to sit down in a standard chair (a seat height of 43 cm from the floor) with no armrests, with hands across their chest and feet slightly apart. From this position, the participant was asked to stand up. If the participant did manage to get up without using their hands, they were asked to get up and sit down five times as quickly as possible, still without using their hands. The execution time (s) was recorded in seconds with one decimal using a stopwatch. It was also recorded whether the participant had managed to get up from the chair five times in a row with or without using his hands. The test was discontinued if not completed in 60 seconds or if it posed any risk to the participant's safety. Its test-retest reliability has been reported as good to very good in most populations and settings [318]. Sainio et al. [319] have reported intra-class correlation coefficient (ICC) 0.75 for chair stand test in untrained Finnish people aged 55–87.

Static balance test (Studies III–IV) has been previously used in the population-based FINRISK study in 2007 [320]. Static balance was measured while the participant was standing in a tandem position (one foot after the other) and in one-leg standing position. In both positions, the participant stood on a firm or soft platform with eyes either open or closed. The participant was supposed to stand in each position for as long as possible, but for a maximum of 20 seconds. The test battery included eight subtests. The subtest that best sorted out study groups was standing with one leg on firm ground with eyes closed, and thus it was chosen for further analyses. The execution time was recorded in seconds (s).

Walking speed (Studies III–IV) was measured over 6.1 meters [321]. Start and finish lines were marked out on the corridor floor with coloured tape. The participants were asked to walk the distance as fast as they could, starting from a standstill behind the start line and continuing at full speed beyond the finish line. They could use walking aids if they normally used them when walking. We recorded the number of steps taken by the participant and speed in meter per second (m/s). The results were also presented as kilometres per hour (km/h). The intra-class correlation coefficient (ICC) 0.77 for walking speed in same distance has been reported among untrained Finnish population aged 55–87 years [319].

20 metre running test **(20mRT)** (Study II) was used to measure maximal anaerobic running power [322, 323]. It was measured with a flying start, and the first five metres were omitted from the calculation of the running time. Further instructions were to sprint in a straight line and keep sprinting maximally until after the 20-m mark was reached. A participant had three attempts in the test of running speed, with one to three minutes' rest between attempts. The shortest time of the running test was included in the statistical analyses. The intraclass correlation coefficient in a flying 20-m sprint has been shown to be 0.98 [324].

4.4.3 Measures of activities and participation (performance)

Performance regarding changing basic body position (d4103–d4106), maintaining body position, other specified (d4158), carrying, moving and handling objects (d4308); fine hand use (d4400), hand and arm use (d4452), walking (d4500, d4502–d4503), moving around (d4551–d4552) and doing housework (d6402) were evaluated by the **Activities-Specific Balance Confidence (ABC) Scale** [325] (Studies III–IV) (Figure 2). The Finnish translation of the ABC Scale was made following the procedure by Beaton et al. [326]. The ABC Scale is a subjective 16-item self-report measure of confidence in executing various daily activities without falling or experiencing a sense of unsteadiness among elderly adults [325]. Items are rated on a rating scale that ranges from 0 (non-confidence) to 100% (complete confidence). The overall score is calculated by adding up the item scores and then dividing this by the total number of items. A score of less than 68% indicates low mobility [325]. Excellent test-retest reliability for ABC scale in two-week interval ($r = 0.92$; $p < 0.001$) [325] and excellent internal consistency (Cronbach's alpha = 0.96) [327] have been reported.

In the present study (Studies III–IV), performance in the activities and participation component (d920 Recreation and leisure) was assessed by two **questionnaires of Leisure Time Physical Activities (LTPA)** (Figure 2). Past (1985) (Study IV) and current (2008) (Studies III–IV) LTPA of the previous 3 months was evaluated by a structured and validated questionnaires [328, 329] asking the average intensity, duration and frequency of the physical activities.

Intensity of LTPA was asked by the following question:

"Is your physical activity (physical exercise) during leisure time about as tiring (intensive) on average as?

1 = walking (4 metabolic equivalent [MET])
2 = walking and jogging alternately (6 MET)
3 = jogging (10 MET)
4 = running (13 MET)"

Duration of LTPA was asked by the question:
"What is the mean duration of your average physical exercise session?

1 = less than 15 minutes
2 = 15–29 minutes
3 = 30–59 minutes
4 = 1–2 hours
5 = more than 2 hours"

Frequency of LTPA was asked by the question:
"How many times per month do you participate in physical exercise?

1 = less than once a month
2 = 1–2 times in a month
3 = 3–5 times in a month
4 = 6–10 times in a month
5 = 11–19 times in a month
6 = more than 20 times in a month"

For each intensity category, a metabolic equivalent value (MET value; 1 MET = 3.5 ml VO_2 / kg / min or 1 kcal / kg / h) [330] was determined. The volume of LTPA was expressed in MET hours (METh), which was calculated by multiplying the intensity (MET), duration and frequency.

4.4.4 Personal factors

A trained study nurse performed the physical examinations including assessment of *height* and *weight* (Studies I-IV), as well as blood sampling (Studies III–IV). Height was measured barefooted with a stadiometer using an accuracy of 0.1 centimetres. Body weight with accuracy of 0.1 kg was determined with a digital scale (Seca Delta Model 707 patient scale, Seca, Hamburg, Germany) in light indoor clothing and barefoot. *Waist circumference* (Studies III–IV) was determined midway between the anterior superior iliac spine and lower edge of the rib cage in a relaxed standing posture to an accuracy of 0.5 cm. *Body fat percent* (Studies III–IV) was calculated as fat mass (kg) divided by body weight (kg) converted to percent. *Lean body mass* (Studies III–IV) with an accuracy of 0.1 kg was assessed by an electrical bio impedance method (In Body 3.0, Biospace, Soul, South Korea).

The participants were asked to rate their general health and fitness on a five-point **Likert Scale** (poor, fairly poor, average, fairly good, good) [331]. In the study II, a self-rated health scale (SRH) was compartmentalized by categorizing response scores 1–3 as fairly poor health, score 4 as fairly good health and 5 as good health. Correspondingly, self-rated fitness (SRF) scales were compartmentalized by categorizing response scores 1–2 as fairly poor, score 3 as average and 4–5 as fairly good. For the analyses of the study III, response scores 3–5 were unified as 'average or fairly poor' in variables SRH and SRF. No responses were found in score 5 and very few responses in score 4.

4.5 Statistical analysis (Studies I–IV)

Statistical analyses were completed using the SPSS version 22.0 for Windows statistical program, the Stata/SE 13.1 and 14.2 (Stata corp., 4905 Lakeway Dr, College Station, TX 77845, USA) and SAS 9.3 software (SAS Institute Inc., Cary, NC, USA). Data of baseline personal factors, physical measurements, LTPA and ABC Scale of the study population were reported as mean values (standard deviation, SD; 95% confidence intervals, CI for differences, Δ) and/or percentages. The normal distribution of the variables was tested with Shapiro-Wilk Statistics ($n < 50$) or Kolmogorov-Smirnov Statistics ($n > 50$). Statistical significance was determined with p-value of less than 0.05.

Study I

Intra-class Correlation Coefficient ($ICC_{3.1}$) [332] (a two-way variance analysis for repeated measures) with 95% CI was used to estimate the relative reliability of ATA. ICC values ≥ 0.80 reflected high reliability and values of those < 0.60 were interpreted as poor reliability [333]. The Minimal Detectable Change at the 95% confidence interval (MDC_{95}) was calculated using the Standard Error of Measurement (SEM) coefficient to estimate the minimum amount of change between test sessions according to Atkinson and Nevill [334] with the following formula: $SEM \times 1.96 \times \sqrt{2}$. If change is smaller than $MDC_{95,}$ it cannot be reliably interpreted as real change in the score for an individual [335]. Cronbach`s alpha (α) was used to determine the between-subject reliability of ATA. The absolute reliability was assessed by using SEM, Coefficient of variation (CV) and Bland and Altman's 95% limits of agreement (LOA) (mean difference ± 2 SD) [336]. SEM was calculated to estimate the amount of measurement variability within the individual score as follows $SD \times \sqrt{1-ICC}$ [332]. It was used to evaluate the consistency of measures by calculating CV coefficient ([SD / mean] x 100). The sensitivity of ATA was evaluated by calculating Smallest Worthwhile Change (SWC) determined by multiplying the between-subject SD by 0.2 [337]. If the SEM is less than the SWC, the ability of the test to find change (sensitivity) is "good". If the SEM equals the SWC, the test may be sensitive enough and “useful”, but if the SEM is greater than the SWC, the test is rated as "marginal" [338]. Analyses of linear regression between performance times at test sessions (1–3) were performed by using SPC, which is based on the supposition that both measurements have random errors and that they are relatively equal. For that reason, SPC analysis gives a more realistic approach to the comparison of two or more measurements than that of the ordinary regression analysis [339]. The differences between the execution times of ATA at various test sessions were analysed by using the paired sample t-test.

Two variables were taken account from the execution of ATA: number of errors and execution time (s). The effect of error on the execution time of ATA has been previously calculated with bigger data (unpublished). The results showed that one error in the execution of ATA gives a benefit of about 1% into execution time. We assume that there is a negative linear relationship between the number of errors and the execution time in healthy people when a person's optimal execution speed is exceeded. This assumption can be applied only when the number of errors is small (≤ 5 errors). Every execution error increased the execution time of ATA by 1%. The results of ATA were analysed both with the original and adjusted execution times and the genders were separated for all further analysis.

Study II

Because of anatomical, neuromuscular and biomechanical differences between the genders [340], all results for women and men have been analysed separately. The genders were compared by a t-test for numeric variables and by a chi-square test for categorical variables. The execution times of ATA are expressed by age groups for women and men. The number of participants in some sub-groups of five-point SRH and SRF scales became small and therefore the sub-groups were combined resulting in higher statistical power. Pearson's correlation coefficients (r) were calculated for mutual correlations of execution time of ATA, age, height, BMI, jumping height, jumping length, and running speed. The results of those were interpreted based on the following thresholds: 0–0.09 = trivial, 0.10–0.29 = small, 0.30 -0.49 = moderate, 0.50–0.69 = large, 0.70–0.89 = very large, and ≥ 0.90 = nearly perfect [341]. Multiple regression analysis was used to assess the multivariate influence of personal factors (age, height, SRH and SRF), BMI, LTPA, power-type strength of lower extremities (SJ and SLJ) and running speed (20mRT) as predictors of agility. Any participants that reported a pain in lower extremities were excluded from regression analysis.

Study III

Between the groups, the comparison of personal factors, strength, and mobility variables were calculated with analysis of variance. The comparison of strength and mobility variables was adjusted for age and BMI. Correlations between the agility and independent variables were expressed with Pearson's product moment correlation coefficients (r). The strength of the correlation coefficient was interpreted based on the definition by Hopkins [341], where 0–0.09 = trivial, 0.10–0.29 = small, 0.30–0.49 = moderate, 0.50–0.69 = large, 0.70–0.89 = very large, 0.90–0.99 = nearly perfect and 1 = perfect. The between the groups comparison of correlation coefficient was evaluated with Fisher's z-transform. In order to test whether the association between agility and independent variables was similar between three groups, the interaction term was applied in linear regression analysis by the independent variable. The multiple linear regression analyses were done using pooled data of the participants (n = 97) in order to compute variance in agility explained by personal factors and LTPA (Model 1), muscle strength (Model 2), or mobility (Model 3). All the statistically significant independent variables from the Models 1–3 were included in a combined model. All continuous independent variables were standardized before the analysis.

Study IV

Comparison between the three groups of study was calculated with multiple linear regression analysis with pre-specified contrasts. P-values were corrected using Bonferroni method for multiple comparisons (endurance and power sports and their controls) and for multiple testing (five tests of mobility, three tests of strength and ABC Scale). All models were adjusted for age because the variances between the groups varied and for BMI because there was a significant difference between the groups. Both age and BMI have been found to be important confounding factors for mobility and physical functioning [342]. In the case of the violation of the model (e.g. non-normality), a non-parametric bootstrapping with 5,000 replications was applied. For the bootstrap based analyses, a normal based 95% CIs are shown in the tables 2 and 3. Significant results were also further adjusted for LTPA and chronic diseases.

5 RESULTS

5.1 Consistency of the Agility Test for Adults

The results of the ATA seemed to be more consistent in men than in women. Therefore, executions of the ATA were analysed separately for women and men (Study I).

The consistency of ATA was evaluated in the study 1. The results of repeatability in terms of ICC, 95% LOA, SEM and CV are summarized in the table 3. The ICC coefficients were greater than 0.90 in 8 parameters for test-retest reliability of ATA in women and men. The narrow range in CI_s among both study groups also indicated good relative reliability.

The CV of the measures over the same-day and the one-week intervals ranged from 4.78% to 5.98% in women and from 4.27% to 5.02% in men for adjusted execution times of ATA. The CV coefficients of agility execution time in our study better fulfilled the demand of the reliability margin of 5.0% for same-day interval than for one-week interval. The within-subject reliability as shown by the CV was generally found to be high.

The absolute reliability coefficients, SWC and the MDC_{95} for the same-day and the one-week performances are presented in the table 3 including original and adjusted performance times. LOA coefficients were lower in same-day comparison than in one-week comparison both in women and men. The difference in the scores for both interval comparisons appeared evenly above the zero point. The mean difference (bias) ± 95% LOA_s of the reliability data of ATA were higher in women than in men.

The SEM_s for ATA were about 0.2 seconds in both sexes. The women had these values for a little more than 0.2 seconds in same-day comparison. The SEM for adjusted time of ATA execution was 2 times higher (same-day) in women than that in men. The SEM_s of women equalized the level of men in one-week comparison. Based on the sensitivity analysis, the ability to detect small changes of execution can be rated as ‘good’ in one-week comparison (SEM < SWC). Same-day reliability analysis showed that sensitivity was ‘marginal’ for women but ‘good’ for men.

The minimal detectable change provides an estimate of the magnitude of the change found (responsiveness) in the reliability data for the ATA test. In the same-day executions, the MDC_{95} value in women was double that in men, but no difference was found in the one-week executions. For example, the responsiveness findings with regard to the one-week execution times of ATA showed a MDC of 0.56 seconds in women and of 0.51 seconds in men. These results indicate that changes in the ATA need to be at least one second before a real change, rather than a change in fluctuation, can be reliably concluded.

Linear regression analysis using method of standardized principal component (SPC) showed high correlations (≥ 0.88) between the test sessions (test 1 is baseline, test 2 one-week later and test 3 half an hour after test 2).

Table 3. Results of repeatability measures, SWC and MDC95 for the ATA test (s) with continuous test variables (Study I).

	ICC (CI)	95% LOA	SEM	CV (%)	SWC	MDC_{95}
Women						
Same-day						
original time	0.93 (0.83–0.97)	0.59 ± 2.33	0.23	4.71	0.24	0.64
adjusted time	0.91 (0.80–0.96)	0.64 ± 2.54	0.27	4.78	0.26	0.76
One-week						
original time	0.95 (0.88–0.98)	0.78 ± 2.25	0.18	5.73	0.23	0.51
adjusted time	0.94 (0.87–0.98)	0.84 ± 2.34	0.20	5.98	0.24	0.56
Men						
Same-day						
original time	0.95 (0.89–0.98)	0.40 ± 1.71	0.14	4.29	0.17	0.37
adjusted time	0.95 (0.89–0.98)	0.41 ± 1.69	0.13	4.27	0.17	0.37
One-week						
original time	0.94 (0.85–0.97)	0.58 ± 2.04	0.19	5.07	0.21	0.52
adjusted time	0.94 (0.86–0.97)	0.58 ± 2.03	0.19	5.02	0.21	0.51

ICC = Intra-class Correlation Coefficient; CI = Confidence Interval; LOA = Limits of Agreement; SEM = Standard Error of Measurement; CV = Coefficient of Variation; SWC = Smallest Worth While Change; MDC_{95} = Minimal Detectable Change at 95% confidence interval.

5.2 Determinants of capacity of agility

Cross-sectional data on 149 women and 84 men (Study II) with a mean age of 43 years and 44 years, respectively, were analysed. There were no significant differences in mean age (p = 0.314), in self-rated health (p = 0.479) and fitness (p = 0.891) (Table 2) and in self-reported pain of lower extremities (p = 0.131) between women and men. Two-thirds of women were normal weight while two-thirds of men were overweight (Table 4).

Table 4. Distribution of agility, running speed, jumping height and length, BMI, pain in lower extremities and LTPA among women and men (Study II).

	Women	Men	*P*-value
Agility (s)	14.8 (3.1)	15.6 (3.0)	0.060
20mRT (s)	3.6 (0.4)	2.9 (0.3)	<0.001
VSJ (cm)	18.7 (4.1)	27.6 (4.9)	<0.001
SLJ (cm)	165.7 (22.4)	225.5 (25.3)	<0.001
BMI			<0.001
normal weight (%)	64.8	22.8	
overweight (%)	26.1	58.2	
obese (%)	9.2	19.0	
Pain in lower limb (%)	26.4	17.5	0.131
Leisure time physical activity			0.046
LTPA (%)	81.3	91.3	
No LTPA (%)	18.8	8.8	

Values are means (± SD) and percentages. *P*-values compared to women.

Multiple regression analyses (Table 5) were performed for those continuous independent variables (age, BMI, jumping height, jumping length, running speed) that were found to be correlated with the agility (Study II). Also, self-reported leisure time physical activity and self-rated health and fitness were included in the analyses. Only participants with no self-reported pains in the lower extremities were eligible for the regression analyses. The first multiple regression analysis revealed that a one SD unit increase in age was associated with an increase of 0.13s in agility ($p = 0.003$) while a one SD unit increase in self-rated good or fairly good health was associated with decreases of -1.94s and -0.46s in agility ($p = 0.031$) in women. Age and self-rated health explained 14.6% of the total variance of the executed time of agility among women. The executed time of the ATA was slower among the men who were older, and they had less self-reported LTPA. In this model, common variance between independent variables (age and LTPA) and agility was 14.1% ($p = 0.006$) in men. After entering jumping height and length, and running speed into model 2, an increase of SD by one unit in jumping length was associated with a decrease of -0.07s ($p < 0.001$) in women and with a decrease of -0.04s in men in executed time of agility ($p = 0.001$). Jumping length explained 25% ($p < 0.001$) of total variation of agility in women and 15% ($p = 0.001$) in men.

Table 5. Determinants of agility (Study II).

Predictor	beta	SE beta	p-value	ModelR^2	Model
Agility in women (n = 106)					
Age	0.13	0.03	0.003		
Self-rated health			0.031		
good	-1.94	0.87			
fairly good	-0.46	0.87			
fairly poor	*0.00			0.146	0.001
Jumping length	-0.07	0.01	<0.001	0.246	<0.001
Agility in men (n = 66)					
Age	0.10	0.04	0.012		
LTPA			0.031		
yes	-2.54	1.15			
none	*0.00			0.141	0.006
Jumping length	-0.04	0.01	0.001	0.153	0.001

Model 1 shows the contribution of personal factors and self-report physical activity (LTPA) as predictor variables for agility among both genders. Model 2 indicates the results after entering jumping height, jumping length and running speed to the Model 1.

*Reference category. $P < 0.05$ statistically significant.

The associations between results of the ATA and personal factors, BMI, muscle strength and power, and tests of mobility were similar between the endurance and the power athletes and the controls (Study III). Therefore, the multiple linear regression analyses were done using pooled data of the participants (Table 6). The total variance in executed times of agility explained by age ($p = 0.001$) and self-rated health ($p = 0.031$) was $R^2 = 17.2\%$ ($p < 0.001$) in the participants. After entering jumping height ($p < 0.001$) and hand grip strength ($p = 0.622$) into model (no. 2), the explained share of the variance increased by 2.2% into 19.4% ($p < 0.001$) in executed times of agility. Adding the static balance ($p = 0.503$), chair stand ($p = 0.943$), walking speed ($p = 0.265$) and self-reported balance confidence scale ($p = 0.025$) into model (no. 3) increased explanatory power only with a minor, statistically insignificant amount ($R^2 = 4.6\%$; $p = 0.081$). The independent variables significant in models 1-3 were jumping height, ABC scale, age and SRH. These were entered to the combined model, and explained 26.4% ($p = 0.001$) of the total variance in executed times of the ATA. An increase of SD by one unit in jumping height was associated with a decrease of -0.36 SD in agility (95% CI, -0.56; -0.15, $p < 0.001$) while an increase of SD by one unit in age was associated with an increase of 0.26 SD in agility (95% CI, 0.05; 0.47, $p = 0.021$).

Table 6. Determinants of agility (Study III).

Predictor	beta	95%	CI	p-value	ModelR²	Model
Agility						
Age	0.40	0.18	0.62	0.001		
Height	-0.14	-0.34	0.06	0.176		
BMI	0.18	-0.01	0.37	0.064		
Self-rated health	0.44	0.04	0.84	0.031		
Self-rated fitness	-0.10	-0.48	0.27	0.588		
LTPA	-0.04	-0.23	0.16	0.704	0.172	*P* < 0.001
Agility						
CMJ	-0.47	-0.68	-0.26	< 0.001		
Hand grip	-0.05	-0.25	0.15	0.620	0.194	*P* < 0.001
Agility						
ABC scale	-0.34	-0.63	-0.04	0.025		
Static balance	-0.07	-0.27	0.13	0.503		
Chair stand	-0.01	-0.34	0.32	0.943		
Walking speed	-0.17	-0.46	0.13	0.265	0.046	0.080
Agility						
Age	0.26	0.05	0.47	0.016		
ABC scale	-0.16	-0.43	0.11	0.240		
CMJ	-0.36	-0.56	-0.15	0.001		
Self-rated health	0.25	-0.04	-0.54	0.095	0.264	*P* < 0.001

BMI, body mass index; LTPA, leisure-time physical activity; CMJ, countermovement jump; ABC scale, Activities-specific Balance Confidence scale. $P < 0.05$ statistically significant.

5.3 Feasibility of the Agility Test for Adults

We evaluated the feasibility (Study III) of the ATA by comparing participants who were unable to execute the ATA but were able to execute other mobility tests with those participants who were able to execute this test. The participants, who executed the ATA, had 20.9% faster executed time (11.5s; 13.9s, respectively) in the chair stand and 37.1% faster executed time (3.5s; 4.8s, respectively) in the walking speed than the participants had who were unable to execute the ATA. The participants, who were unable to execute the ATA, had 12.8 percentage points less confidence in their own balance (76.3%; 89.1%, respectively) to perform daily activities than the participants had who executed the ATA (Study III, Table 3).

5.4 Level of agility, muscle strength and leisure time physical activity

The mean age of the former endurance athletes was 76.2 years, and that of the former power athletes was 74.9 years. Mean age in the control group was 75.4 years. No significant differences were found in age between the study groups (Table 2). Mean (SD) BMI of the endurance athletes was 24.9 (3.5) kg/m^2 and of the power athletes 28.0 (3.7) kg/m^2 while the corresponding value for the controls was 25.9 (3.4) kg/m^2. The power athletes had the highest BMI ($p = 0.003$ compared to the controls). The former elite endurance athletes were more physically active than the controls both in 1985 ($p < 0.001$) and 2008 ($p < 0.001$). There is also a difference between the power athletes and the controls in relation to the volume of their past LTPA ($p = 0.030$). The distribution of body composition, blood pressure, glucose and lipid metabolism, and self-reported past and current LTPA among the participants (n = 150) categorized according to sport group is represented in the table 7 (Studies III–IV).

After adjustment for age and BMI, the power athletes had faster executed time of ATA than the controls had (Δ Mean -3.6 s; 95% CI -6.3, -0.8). Adjustment for current leisure time physical activity and prevalence of diseases made this difference non-significant (p = 0.214). No significant age and BMI-adjusted study group differences appeared for chair stand, static balance, walking speed or self-rated ABC-scale. The height of vertical jumps (VSJ and CMJ) was higher in the power athletes than in the controls (Δ Mean 4.4 cm and 4.0 cm; 95% CIs 2.0, 6.8 and 1.7 and 6.4, respectively) when results were adjusted for age and BMI. No significant difference was observed between the endurance and the control groups in vertical jumps or in hand grip strength. Considering the current LTPA and chronic diseases in the adjusting process did not improve explanatory power of the model. Table 8 shows the results of mobility, self-reported ABC scale, jumping height and hand grip strength (Study IV).

Table 7. Distribution of body composition, blood pressure, glucose and lipidmetabolism, and self-reported past and current LTPA (Studies III–IV).

	Endurance n = 50			Power n = 50			Controls n = 50	
BMI (kg/m²)	24.9	(3.5)	0.150	28.0	(3.7)	0.003	25.9	(3.4)
Waist circumference (cm)	94.1	(10.2)	0.097	99.6	(11.9)	0.305	97.4	(9.7)
Fat percentage (%)	23.7	(6.2)	0.438	26.6	(5.4)	0.097	24.7	(6.0)
Lean body mass (kg)	56.8	(5.6)	0.271	61.4	(9.3)	0.026	58.0	(5.3)
Systolic BP (mmHg)	141.5	(22.2)	0.426	144.8	(19.5)	0.992	144.9	(19.7)
Diastolic BP (mmHg)	79.1	(9.4)	0.858	80.5	(9.1)	0.542	79.4	(8.5)
Total cholesterol (mmol/l)	5.2	(0.9)	0.025	5.0	(0.9)	0.392	4.8	(0.9)
LDL cholesterol (mmol/l)	3.3	(0.8)	0.012	3.0	(0.7)	0.249	2.9	(0.8)
HDL cholesterol (mmol/l)	1.4	(0.3)	0.640	1.3	(0.4)	0.665	1.4	(0.3)
Triglycerides (mmol/l)	1.2	(0.4)	0.498	1.3	(0.4)	0.688	1.2	(0.5)
Fasting plasma glucose (mmol/l)	6.1	(0.5)	0.377	6.4	(1.3)	0.520	6.3	(0.7)
2-hour plasma glucose (mmol/l)	7.1	(2.2)	0.020	7.7	(2.4)	0.245	8.4	(3.0)
Fasting serum insulin (μIU/ml)	75.3	(11.7)	0.281	84.8	(16.4)	0.013	77.9	(11.5)
Past LTPA volume (MET-h/week)	45.7	(48.0)	< 0.001	35.4	(35.0)	0.030	15.7	(25.6)
Current LTPA volume (MET-h/week)	43.2	(34.5)	< 0.001	26.1	(23.9)	0.361	18.9	(15.1)

Unadjusted data expressed as means (± SD). *P*-values compared to controls. BMI, body mass index; BP, blood pressure; LDL, low-density lipoprotein; HDL, high-density lipoprotein; Past (1985) and current (2008) LTPA, leisure-time physical activity; MET-h/week, metabolic equivalent hour per week.

Table 8. Distribution of mobility, ABC scale, jumping height and hand grip strength among participants divided into different athlete and control groups (Studies III–IV).

	Endurance n = 50			Power n = 50			Controls n = 50			Endurance vs Controls			Power vs Controls		
Mobility	**n**			**n**			**n**			**Δ Mean**	**95%**	**CI**	**Δ Mean**	**95%**	**CI**
Agility (s)	35	21.3	(7.9)	30	19.3	(3.9)	37	22.1	(5.8)	-0.9	-4.4	2.7	-3.6	-6.3	-0.8
Dynamic Balance (s)	40	4.6	(2.8)	36	4.9	(4.2)	37	4.4	(3.0)	0.2	-1.4	1.7	0.8	-1.1	2.8
Walking speed															
(m/s)	50	1.6	(0.3)	48	1.6	(0.5)	50	1.6	(0.3)	0.1	-0.1	0.2	0.1	-0.1	0.2
(km/h)		5.9	(1.1)		5.8	(1.8)		5.7	(1.1)	0.2	-0.2	0.7	0.2	-0.4	0.8
Chair stand (s)	50	11.8	(2.4)	49	12.4	(3.7)	50	12.7	(3.7)	-1.1	-2.5	2.8	0.2	-1.9	1.7
ABC-scale (%)	50	82.2	(16.6)	50	86.4	(16.3)	50	85.0	(15.6)	-3.0	-11.2	5.2	1.9	-6.4	10.1
VSJ (cm)	42	16.9	(5.5)	32	19.3	(5.3)	40	15.4	(4.4)	1.4	-1.0	3.7	4.4	2.0	6.8
CMJ (cm)	42	18.2	(5.9)	31	20.5	(5.0)	39	17.1	(4.9)	1.2	-1.4	3.8	4.0	1.7	6.4
Handgrip strength (N)	50	437	(124)	50	491	(128)	50	465	(87)	-1.8	-6.6	3.0	1.4	-3.7	6.4

Results are adjusted for age and body mass index (BMI) and presented as means (± SD) as well as means and 95% confidence intervals (CI) for differences (Δ).

6 DISCUSSION

6.1 Main findings

The present study evaluated 1) the test-retest reliability of the ATA and quantified the Minimal Detectable Change at the 95% confidence interval (MDC_{95}) (Study I), 2) the determinants of the capacity of agility (Studies II-III), 3) the feasibility of the ATA (Study III) and 4) the effects of participation in competitive sports in young adulthood or life-long leisure-time physical activity on the present level of physical functioning (Study IV). The International Classification of Functioning, Disability and Health (ICF) was used as a framework to define the measures of physical functioning (Studies II-IV).

The means of relative and absolute reliabilities using several coefficients increased possibilities to compare results from previous studies. The main findings of this study showed that the ATA was stable and reliable in untrained middle-aged women and men. Additionally, the values of MDC_{95} of repeated ATA executions were low in 28–55 -year-old people.

Jumping length was found to be the main determinant of agility; however, the total variances in agility explained by jumping length were 25% and 15% for physically inactive or active women and men, respectively. Jumping height and age were the main determinants of agility regardless of previous physical activity for three months or type of sports in the cohort of men aged 66-91 years.

The data of this study allowed assessing the feasibility of the ATA for people aged above sixty years. The oldest man who executed the ATA test successfully was 85 years old. The results of this study also suggest that the ATA seems to be more sensitive to reveal physical disorders of a participant than the other commonly used mobility tests.

The comparison of physical functioning level between former elite endurance and power athletes and their controls showed that former elite power athletes, but not former elite endurance athletes, had better age- and BMI-adjusted executed times in agility than the controls. After LTPA- and chronic disease-adjustments this difference became non-significant (p = 0.214). No differences in the functions of static balance, walking speed, chair stand and hand grip strength, and in self-reported activities-specific balance confidence scale were detected between the athletic groups and the control group.

6.2 Consistency of the Agility Test for Adults

The ATA has been designed and developed (Study I) to evaluate the capacity of agility more comprehensively than previously used agility tests do. Based on a systematic literature review, most agility tests have been developed in a sport-specific context and for elite athletes. Studies on agility in middle-aged or older people are rare. In this thesis the main concern in the ATA test was adequate consistency in terms of the test-retest procedures including several coefficients. Using those coefficients increased possibilities to compare results from previous studies.

One focus of the present study was to evaluate relative and absolute test-retest reliability for the ATA (Study I). Based on the original and adjusted executed times of the ATA, further calculations were made to express the ICC_s with 95% CI_s (relative reliability) and the absolute reliability coefficients as 95% LOA_s, SEM and CV coefficients. Overall, the results showed good reliability in both short and long intervals. Good relative reliability defined as ICC > 0.90 was obtained for the ATA in women and men. The reliability of each measure of agility was similar to that found in previous studies performed with younger high-performance athletes than participants of this study (Study I).

Although test-retest correlation coefficient is a good measure of reliability, within-subject error reported in this study as SEM and CV, would be a better measure [343]. The differences are expected to influence the results due to e.g., variability in the executions of participants. The SEM_s and CV_s for the ATA varied between women and men. Values of those were smaller among men than women because of the better homogeneity of the male group with respect to neuromuscular and biomechanical differences between the genders [340]. This discrepancy may reflect the difference to execute tasks involving agility between women and men. The variation represented by standard error of measurements comes from several sources, but the main source is usually biological function [343]. Personal factors such as motivation to execute tests successfully, may also have affected the test-retest reliability. Fatigue was an unlikely source of error considering this sample consisted of healthy participants and simple procedure of measurement. However, the CV coefficients of agility fulfilled the demand of the reliability margin of 5% [343] for same-day interval but those for one-week interval nearly attained this margin. These coefficients denote accuracy of measurements and sensitivity of the method. In other words, the smaller the within-subject variation is, the better is the accuracy of a single measure, which means that the sensitivity of the method is better. In general, the absolute reliability values were good.

The SEM values showed the range in which an individual's true score is likely to lie [332, 334] indicating the execution times of the ATA were stable both for short and long intervals in this study. It has been recommended to extend the analyses of the absolute reliability using the SWC which represents the minimal individual change that can be interpreted as real with an acceptable level. In this context, this study compared SEM_s with SWC_s resulting that the sensitivity of the ATA could be rated as 'good' (SEM < SWC) in the one-week comparison. Same-day reliability analysis showed that the sensitivity of the ATA was 'good' (SEM < SWC) for men but 'marginal' for women (Study I). However, the results provide evidence that the ATA test has a good ability to detect real changes in the capacity of agility in untrained women and men.

The responsiveness is defined as the ability of a measure to evaluate clinically important changes over time [344]. Minimal detectable change (MDC_{95}) (or responsiveness) of the ATA was evaluated as a criterion to determine whether a real change has occurred between test and retest. In the ATA test, the MDC_{95} of 0.51s (0.56s in women) means that a change of less than 0.51s cannot reliably be interpreted as a real change for the individual compared with change fluctuations (Study I). The MDC values found have simplified the interpretation of score changes in clinical practice or in future studies. It is important for clinicians and physical trainers using the ATA to know that a change of > 0.51 seconds occurred, e.g. after rehabilitation with untrained men is necessary to be 95% certain that the change in execution shows up improvement and exceeds errors of measurement.

In summary, ATA is simple, quickly executed and not too physically demanding. Further, no special devices are needed. According to the framework of our study, execution of ATA requires the speed and accuracy of movements (e.g. strength, power and dynamic balance), perception and decision making (e.g. visual information), performance technique (e.g. foot placement) and ability for quick reactions, i.e. action (e.g. starting and stopping movement)(Study I, Figure 2). The essentials of ATA are accuracy and speed of movement. The term 'accurate' means that the movement should be planned and controlled. The participant was instructed to do the ATA test as accurately and as quickly as possible, meanwhile controlling movements to minimize errors. For these reasons, ATA can be considered an appropriate method for screening early signs of the declined agility characteristics among the middle-aged or people who would benefit from exercise therapy. Clinicians and physical trainers can use the reliability coefficient obtained by MDC_{95} as the level beyond which a true change will appear due to physical training focused on agility. The acceptable test-retest reliability of the ATA found in the present study indicates that it is suitable for both clinical practice and research in untrained adult people.

6.3 Determinants of capacity of agility

The determinants between agility and muscle function of lower extremities evaluated among young, athletic or regularly exercising college-aged participants are well known [6-8, 345, 346] but there is little research on the key determinants of agility among untrained adults. This study complements knowledge of agility giving tips to plan the content of exercise session or to choose adequate methods for rehabilitation improving or maintaining the capacity of agility focused on adult people. The design of this study was conducted to achieve information on the muscle power function and speed, personal ICF factors and BMI, self-reported pain of lower extremities and leisure time physical activity as determinants of agility in physically inactive or active women and men (Study II).

There were small positive correlations between agility, age and BMI in women; whereas moderate correlation coefficients were found between agility and age in men. The relationship between agility and BMI in men was minor. The results from this study disagreed with those of Nimphius et al. [9]. They found strong positive correlation between body weight and change of direction in young female softball players and suggested that the smaller-sized athletes excel in the variables of speed and change of direction (CODS). It is important to note that cognitive functions are absent in the CODS test, thus this kind of test and the ATA are not comparable. The study of the relationship between BMI in mid-life and disability in old age evaluated with questionnaires showed that maintaining a healthy body weight in middle-age reduced the risk of disability in later life [347]. Taking account of this, it is justified to measure BMI in middle-aged persons in order to avoid the possible confounding of illness-associated weight loss in elderly people. Did BMI have effect on agility after all in this study? Two-thirds of women were normal weight while two-thirds of men were overweight, and mean execution times of agility were better in almost every age group of the women compared to the males (Study II, Table 3). However, the analyses in this study showed that BMI does not play an important role for adult women and men in agility, which is supported by that of previous research evaluating physically active men [8].

Multiple regression analyses were used to determine the strength of the independent associations found between agility and the above-mentioned variables. When the effects of personal ICF factors and self-reported LTPA on the capacity of agility were evaluated among the women, the strongest predictors were age and self-rated health ($R^2 = 0.146$), whereas in men the best predictors were age and LTPA ($R^2 = 0.141$). These findings indicated that combined personal factors such as age and self-rated health, as well as age and LTPA had some effect on the capacity of agility. It can be suggested that the neuromuscular function declines with age, which generally impairs the capacity of agility. This point of view is partly supported by the fact that slower execution time in ATA is associated with older age in both genders, and with poorer self-reported health in women and with inactivity in men.

The decline of the agility characteristics seems to begin at the age of forty in both women and men (Study II, Table 3). This finding is consistent with a previous study which assessed the capacity of agility in middle-aged female participants [29]. The process of decline in execution time of agility seems to be faster in women after 45 years of age while the decline seems to progress more slowly and regularly among men (Study II, Table 3). Contrary to our results, it has been shown that the deterioration of agility accelerates after 50 years of age in both women and men [28].

In the present study, 81.3% of women and 91.3% of men reported to be physically active during the last three months before the study. LTPA included gardening, moving outdoors and self-care activities as well as bowling in this study. However, slower execution time in ATA is associated with inactivity in leisure time among men. Moderately physically active men were 2.5 seconds quicker in the ATA compared to inactive men. This difference was big because the mean of execution time of agility was only 15.6 seconds. Unfortunately, there was no information on the profiles and the details of LTPA for the participants during their childhood or early middle-age, which limits the interpretation of the results of this study. Basically, the findings partly confirm the knowledge that participation in LTPA is known to be associated with better physical functioning [26], reduces the risk of mobility limitation in midlife [300], and that any kind LTPA is better for physical fitness than inactivity [103].

The results of the present study demonstrate clear relationships between agility (ATA), squat jump (SJ), standing long jump (SJ) and 20m running test (20mRT) (Study II, Table 4). The Pearson correlation coefficients were moderate or large ($r \leq -50$; $r < 50$) in both genders. These findings agreed with those of previous studies ([38, 83] using measures of agility, muscle power and running speed executed by young physically active men. Some studies showed weaker relationships between jumping height, sprint execution and agility [11, 40] than in this study. The used measurement methods would require independent and specific motor skills if the correlation coefficient is less than 0.71 [348]. In practice, the limited relationships between agility and tests of muscle function and speed were determined by the specificity of movement. In other words, each test is a measure of specific movement patterns in this study. Based on these findings, it can be suggested that a little association between agility and physical functions was influenced by e.g. cognitive functions that decreased the effect of physical functions. Furthermore, the differences in results may be partly explained by the different methods to measure agility. However, the findings of this study and literature suggest that agility is a more complex motor skill than jumping or running.

From moderate to large correlation coefficients between ATA and jumping length and height and running speed suggest that the muscle power function and speed of the lower extremities would be important for the capacity of agility. When jumping tests and running speed were entered into regression analysis, the strongest relationship was between agility and jumping length which explained almost 25% of the variance in executed times of ATA in untrained women and men (Study II, Table 5). The explanatory power below 50% indicates that agility and jumping length are independent skills [348]. Our findings are consistent with those of the previous studies [7, 8, 38] even though they studied young athletes or regularly exercising college-aged participants, whereas in this study, the participants were fairly inactive or moderately physically active adult people. The older age and inexperience in speed and power tests among the participants in this study could have been reasons why jumping length was shown to have more explanatory power for the ATA than running speed or jumping height, which both showed insignificant association with the capacity of agility. Both jumping height and jumping length measure power; we suggest that jumping height is a more complicated test for ordinary people than jumping length. Jumping length explained below 25% of agility due to lack of characteristics needed in the ATA, e.g. foot placement, accuracy of movement and particularly to the cognitive components. Previous studies have ended up in a similar conclusion [7, 11, 39].

Jumping length explained below 25% of the variance in execution time of agility in physically inactive or active women and men. These findings and the literature strengthen the assumption that ATA requires also other physical and cognitive functions than evaluated now. Previous studies on the relationships between agility and various cognitive functions have found associations with anticipation, visual processing speed, and kinesthetic recognition of spatial confines [37, 97, 349]. BMI does not play an important role in agility in this population. Physical inactivity could explain the deterioration of agility as well as various biological mechanisms in the ageing process could be linked also to the decline in the capacity of agility.

The relationships between agility, balance and power of lower extremities have been reported in young athletes, but limited information is available on explanatory factors determining the capacity of agility in older persons after their athletic career. Based on previous studies, one may expect that vigorous physical activity during childhood and young adulthood may help individuals to stand up to age-related physical changes as well as to health-related changes better than those individuals without a former history of regular physical activity. Therefore, former elite athletes (Studies III-IV) can serve as a reference when evaluating the effects of life-long physical activity on physical functioning at old age [350]. Even though causality cannot be confirmed in this cross-sectional study, the findings would serve as basis for further analyses. To the best of our knowledge, no previous study has determined the relationships between comprehensive physical measures, personal

ICF factors, self-reported LTPA and ABC scale in a well-described sample of ageing former elite athletes and their matched controls (Study III).

The negative moderate and large correlations between agility and jumping height (CMJ) (r = -0.55 endurance; -0.43 power; -0.40 controls) (Study III, Table 4) were observed indicating that the power of lower extremities appears to have an important role in the capacity of agility among both the athletic and the control groups. Compared to these findings, weaker relationships have been reported both in young people engaged in team sports [7, 11] and in physically active older adults [351]. Similar correlation coefficients as seen in this study have been shown by Alemdaroğlu [6] for young athletes. However, the results of the correlation analyses indicated that the relationship between agility and muscle power function was very similar, regardless of the sport, the age of the participants or the level of physical activity. Our findings may partly be explained by the nature of the ATA including quick jumps both on one foot and on two feet. That demands good interplay between perception, decision making, power of lower extremities and balance. Also, explosive movement, as vertical jump requires that participant generates force and power with appropriate timing and magnitude. In other words, a specific coordination of body segments is required to execute a maximizing jump [352, 353]. No significant relationships were found between the ATA and other mobility tests, as the functions required to execute the agility test differ from the functions required to execute other mobility tests. The significant correlation coefficients between agility, age (r = 0.47) and ABC scale (r = -0.35) were observed only in the controls.

The comparison between the groups of participants, the associations between ATA results, personal factors, BMI, muscle power and strength, other tests of mobility, ABC-scale and self-reported LTPA were similar (p for interaction > 0.07, data not shown). Thus, the multiple regression analyses were done with pooled data (Study III, Table 5). Predictably, age was a significant determinant of agility even within the age-range studied. Longer execution time of ATA was associated with older age and with poorer self-rated health in this study. The influence of age on agility could be a result of decline in the physical and cognitive functioning which generally affects the capacity of agility in the ageing process. This conclusion is supported by previous studies of age-related changes in neuromuscular system [150, 354] and of connection between motor skill and cognitive functions [355, 356]. The decrease in the physical capacity of the elite athletes begins after the age of 40 years [357] due to the loss in the powerful type II-fibre motor units with subsequent muscle atrophy and a loss in muscle power [358]. The cognitive function as the anticipatory motor planning was subject to accelerated and progressive decline beyond the age of 60 years [356]. It can be postulated that this cognitive function could be one of the key mechanisms to execute the ATA successfully.

Thus, this finding may partly explain why there was no difference between the groups in the agility test.

Evidence exists that capacity of agility is more likely to be influenced also by cognitive functions rather than by strength functions alone both in male and female team sport athletes [7, 359]. In a sport-specific context, cognitive functions in agility imply to react quickly and accurately in response to external stimuli [39, 359]. In the test track of ATA, red cross marks and yellow squares act as external stimuli. However, previous findings are indicative of young team sport athletes, so they are not directly proportional to former elite athletes and their matched controls.

Further regression analyses showed that age, jumping height (CMJ), ABC scale and self-rated health proved to be significant independent variables to explain the variance in the capacity of agility. After entering z-scores of those variables into a combined regression model (Study III, Table 5), power of lower extremities (p = 0.001) and age (p = 0.016) were the main determinants of agility regardless of previous physical activity during three months or types of sports in the cohort of men aged 66-91 years. Overall, the strongest independent variables, i.e., jumping height, age, self-reported balance confidence and self-rated health were able to explain about one-quarter (p < 0.001) of the variance in capacity of agility. These findings suggested that the athletes' self-reported average physical activity or career of competitive training and racing, other personal factors or body functions did not appear to provide additional explanatory power on execution of agility among elderly men.

The multiple linear regression analyses showed that countermovement jump was a significant contributor in execution of agility among elderly men. As expected, this finding is in line with the results of study II found in physically inactive or active adult people, who were 30 years younger than the men in this study. CMJ has shown to be the most reliable test for the evaluation of lower extremities power among athletes in different age groups [313]. Hence, jumping height measured by CMJ has shown to be an appropriate test also for older adults [201].

However, to our knowledge, the specific associations between the capacity of agility, mobility, muscle strength and power, personal factors, self-reported activities-specific balance confidence and LTPA studied here have not been reported previously in elderly men aged 66–91 years. Therefore, greater knowledge of the functions that reliably predict the execution of agility could improve rehabilitation strategies to identify early signs of declined agility or monitor changes in the capacity of agility. From a clinical point of view, these results, both in younger and in older persons, show that the power of lower extremities plays an important role in maintaining or enhancing agility. Ageing people will gain benefits by means of training the capacity of agility using explosive movements e.g., ball games or plyometric exercises [360]. The response to such exercises also depends on genetic qualities [150]. Furthermore, especially the muscle power of lower extremities has been assessed as an important predictor of limitations for functional performance tasks such as rising from a chair, stair climbing and walking speed [15, 16, 108].

There are mobility tests that have been used to measure agility in adults and older people. The Timed UP-and-Go (TUG) test has been developed for the evaluation of mobility and balance (as strength and gait stability) among frail elderly persons [99] even though TUG has also been used to measure agility, but may not sufficiently reflect risk factors such as poor vision [361]. Also, the Figure-of-eight (FIG8) has been used to measure agility [96, 362], but it has been classified into Changes of Direction and Speed tests (CODS) since it lacks e.g. cognitive functions [39]. The Ten Step Test (TST) [28] is a modified agility test for older adults. TST is developed to assess a participant's ability to take a quick step in same or different directions. The stepping tests do not necessarily require a large weight shift from side to side. Also, these tests do not meet the requirements for common every day stepping in real life. In fact, they are suitable for evaluating dynamic balance function. The ATA test differs from other mobility tests due to following reasons: the execution of ATA requires e.g. quick processing of visual information, anticipatory and accurate movements, as well as correct and precise type of foot placement. Physiological demands are different. However, according to the reference framework used in this study, the tests like FIG8, TUG or TST are not multidimensional enough to evaluate the functions required by ATA test among middle-aged or older people.

The evaluation of physical functioning is crucial in physiotherapy. Nevertheless, very few studies have attempted to define the meaning of agility in physical functioning in middle-aged or in older people. In this study, there was a possibility to evaluate the capacity of agility and to evaluate the determinants of agility in a unique dataset consisting of former elite athletes and their controls in their senior years. This study showed that agility associates with self-rated balance confidence to perform daily activities (Study III, Table 5). More studies on these potential physiological or psychological mechanisms for capacity of agility are clearly required among older people. Agility has been shown to be one of the basic functions required to independently and safely execute activities of daily living in elderly people [12, 14, 363]. The good capacity of agility can be transferred to the activities of real-life environment in the following way: The before mentioned body functions, e.g. perceptual functions, muscle power or gait pattern, constitute capacity for activities, which are needed e.g., for walking on a congested street, moving around in a crowded shopping centre, or taking the bus without losing balance. Also walking down or upstairs and walking at home without colliding with furniture require people to change their pattern of movement according to task and environment. Patla et al. [364] have reported that a person modifies ongoing movements by processing available visual, vestibular and somatosensory information (as in execution of agility) to avoid obstacles on the ground. These facts give justifiable significance also for the capacity of agility as a part of daily living for example to avoid falls and stumbles among people of all ages.

6.4 Feasibility of the Agility Test for Adults

This study evaluated the feasibility of ATA by comparing participants who were able to execute ATA with those participants who were unable to execute it, but were able to execute other mobility tests (Study III, Table 3). The Chair Stand test evaluates the ability to rise from a chair and sit back down, as well as strength and power of lower extremities. The reference value is 12.6 seconds in the Chair Stand test for elderly aged 70–79 years [365]. Among the participants, the average value was 11.5 seconds for those who were able to execute ATA and 13.9 seconds for those who were not able to execute ATA. The average execution time was also shorter in the walking speed test for participants (3.5 s) who executed ATA than for those (4.8 s) who were not able to do that. All participants, who were not able to execute ATA, were able to execute the other mobility tests. For these above-mentioned reasons, no significant associations were found between ATA and other tests of mobility.

Participants, with no execution time of ATA, had significantly weaker results with larger standard deviations in mobility tests and in the ABC scale than participants who executed ATA. According to this data, ATA could be used among relatively healthy men up to 80 years of age.

6.5 Level of agility, muscle strength and leisure time physical activity

The effects of long-term vigorous physical activity on the health [366–373] and physical functioning [354, 374–377] are well known among former elite athletes. Physical functioning was most often assessed by self-reported questionnaires, but relatively little information was collected through objective measures to evaluate the level of physical functioning in this population. A sample of 100 former Finnish athletes and 50 matched controls was studied in this cross-sectional study (Study IV).

The male former elite power athletes having a history of vigorous physical activity during young adulthood had higher BMI than their matched controls. No differences were observed in BMI between the whole group of the present studied former elite endurance athletes and their controls. Those participants who had highest body mass index have probably had bigger risk for joint disabilities, especially in their lower limbs. This assumption can be made because no differences in the volume of current LTPA between the power athletes and the controls were observed and also previous studies have found a bigger risk for joint disabilities in power sports [371, 374, 378] and an increased risk for osteoarthritis in lower limbs in old age due to competitive sport participation at a young age [371, 379].

The former elite athletes and the controls did not differ from each other in execution of agility (Study IV, Table 2). The diseases such as osteoarthritis of the knee or hip joints, poor vision and neurological disorders, reduced the number of successful agility, jumping and static balance executions more than executions of the other physical tests among participants. These disorders impaired more the executions of agility in former power athletes than in former endurance athletes or in the controls: only 60% of former power athletes (vs 70% of former endurance athletes and 74% of the controls) were able to execute the ATA because the former power athletes had more musculoskeletal or neurological disorders. Same differences between groups could not be seen in other mobility tests. This suggests that ATA could be more sensitive to reveal physical disorders of a participant than the other used mobility tests.

However, one may expect that the power athletes, who have practised competitive sports and have had to focus their training mainly on power, speed and elasticity without ignoring basic endurance training in young adulthood, will maintain a relatively high level of mobility across the lifespan. The same kind of physical functions and characteristics are required also in execution of agility. The capacity of agility has been described as a versatile skill consisting of a variety of body functions including power, balance and cognitive functions [39, 380]. Possibly, the used ATA test can be too demanding and difficult to execute for the study groups of this age. The ATA has been focused on cognitive function demanding quick perception and decision making to choose accurate movement between three types of stepping on the marks. The quick processing of visual, vestibular, and sensomotoric information is a prerequisite for a successful execution of the ATA. This perspective is confirmed by previous results that the perceptual functions may potentially influence capacity of agility [48]. Furthermore, previous studies have observed the effect of cognitive function on speed of lower extremity movement in older populations [2, 381]. Over the last few years, researchers have focused on creating complex agility tests that also include cognitive or decision-making function [54, 382].

Regardless of age, BMI, current LTPA, and prevalence of chronic diseases, the former power athletes jumped 4 cm higher in vertical squat (VSJ) and 3 cm in countermovement jump (CMJ) tests (Study IV, Table 3). The exercise training pattern of power-oriented athletes probably differs from that of endurance athletes. The power type of training seems to promote the neuromuscular function [383]. Sport-related differences might be explained by training background [384, 385], differences in muscle cross-sectional area [384] and by a different muscle fibre type proportions [384, 386, 387] in differently specialized athletes. Genetic differences in muscle fibre types have been shown in young former elite sprint and endurance athletes [386]. Better executions in jumping test in the group of power athletes can be partly explained by the above-mentioned biological and physiological factors of the neuromuscular system. On the other hand, various biological mechanisms in the ageing process are linked to the deterioration in function of muscle power and in the control of dynamic movements. Focusing exercises on high-velocity physical activities would be considered essential for increasing functional fitness in older people.

Some of the athletes have been able to continue with similar exercises for recreation and maintain their physical fitness and functioning. An important consideration is the lack of detailed information on physical activity profiles of study participants during childhood. In addition, specific details on the training programs are not known in young adulthood. In this context, the higher jumping height in the former power athletes than in the controls might be partly explained by participation in competitive power type sports in young age and not by lifelong leisure time physical activity. The current assumption is supported by previous studies that have reported a history of training and competitive sport attenuating the decline of jumping power between elderly male former elite athletes and non-athletic men [209, 377]. It has been also shown that the lower limbs stand up to ageing better than upper limbs among master athletes [388].

Neither the objective test of mobility, hand grip strength nor self-reported balance confidence discriminated the study groups in this study (Study IV). First, the control participants were well-functioning in the context of their age, and had less dysfunction of lower extremities than the former athletes. It could be explained by the fact that the participants with good health and physical functioning were able to take part in this study. Second, the execution of the other physical tests used does not require such demanding motor functions as the capacity of agility or jumping.

6.6 Physical functioning in regard to the ICF classification

All the measures in the present study were described according to the ICF classification (Studies II–IV). The ICF framework provides a suitable and feasible tool to assess functioning for planning interventions, for evaluating their effect [389, 390], and the impact of a health condition or various health related, personal or environmental factors [391–393], as well as evaluating outcomes of rehabilitation and treatment [32, 390, 394]. The process of developing systematic approaches to establish linkages between the ICF and existing measurement methods is necessary to create measurement standards. The ICF can be very helpful in clarifying the concepts in existing measures. It is proposed to facilitate communication between multiple sectors, such as health care, health policy, education, statistics, institute and insurance companies [32]. The ICF can be used to increase the efficiency and communication of research between different domains [390], to improve population health and to produce important information about functioning for health care suppliers and for the planning of health care and services [394, 395]. In all areas of health care and rehabilitation, researchers and clinicians need valid and reliable data about status of physical functioning in order to make informed decisions, to develop and monitor interventions and to improve or maintain physical functioning [32, 390].

6.7 Strengths and weakness of the study

In this study, reliability of the Agility Test for Adults by means of relative and absolute reliabilities using several coefficients has been evaluated. These analyses increased possibilities to compare results with those of previous studies. Unfortunately, there was no possibility to evaluate the reproducibility of the scores when a scale is applied by different raters (inter-rater).

There is no consensus 'gold standard' to measure agility. An agility test similar to that of ATA was not available in this study to compare the results with those of the ATA test. The criterion validity could not be established in this study.

The data of the present study originated from a well-described follow-up study of Former Elite Athletes with matched controls (Studies III–IV). The control group allows reliable comparisons with the athlete groups. This unique dataset contains repeated information of physical activity, health, and physical functioning from young adulthood to old age. The participants were all Finnish men and the sample size of this sub-study was small. The male former elite athletes differ from the general population because they are probably a genetically and biologically selected group that has also been selected regarding physical activity behaviour. Regular physical activity is associated with a lower risk for all-cause mortality which means that the study groups were selected. Some of the participants had chronic illnesses, most of which were found in the former power athletes. Also, only those participants who were able to travel to the research laboratory are included in this study. These selection procedures may have influenced findings of this study.

The current study does not have information on the physical activity level of study participants during childhood nor specific details on the lifelong training models, which limit the interpretation of agility and jumping test results. The intensity of LTPA was structured the same way in studies III and IV. So, the order of MET values remained stable, but the physiological meaning of MET values depends on relative strain into the body. The persons in the study III were 20 years older and their METc was about 2-4 MET less. Perhaps also MET values of activities were also 1-3 METs less. The whole activity scale in the study III is narrower compared with the study IV. This might have some influence on the results.

The self-reported LTPA instead of more accurate measurement, such as accelerometer, and evaluation of body composition by using BMI rather than more accurate measure, such as bio-electrical impedance, could have a weakening influence on the reliability of the present study (Study II). LTPA was measured only by a two-dimensional scale, which is not very sensitive, but specific enough to divide the study population in our study.

The conversion of information from leisure time physical activities used in this study overestimates MET values in older population (Studies III-IV). There was also no information on the LTPA profiles and details of the participants in their later life, which limits the interpretation of the results of the current study. Unfortunately, this study did not include former elite athletes of ball games because it has been shown that training with a ball or ball games can be positively associated with body functions as agility and static balance in physically active women and men. These findings show that sports, e.g. power sports, which do not demand anticipation or decision-making functions, do not develop capacity of agility to same extent as e.g. ball games.

The osteoarthritis of knee or hip joints, poor vision and neurological disorders reduced the number of successful agility, jumping and static balance executions more than executions of the other physical tests among participants (Studies III-IV). Therefore, the study sample was small. On the other hand, failure to execute the ATA due to the abovementioned conditions provides information on capacity of functions needed to execute the ATA successfully. Other selective factors may influence our findings as differences might exist in genetic and biological characteristics regulating the ageing process. However, because the relationships between agility, and personal factors, BMI, LTPA, muscle strength and power, mobility and ABC scale were relatively similar between the aged former athletes and controls, selection bias seems to be less probable.

The design of this study (Studies III-IV) was structured to minimize most sources of measurement error arising from the environment or measurer. Regretfully, we did not have possibility to evaluate the reproducibility of the scores when a scale is applied by different raters (inter-rater). Participants were elderly and most of them lived far away from the research laboratory. For this reason, there was no possibility to increase the number of test sessions. To control the known risks of errors e.g., standardized instructions were used and the same experienced physiotherapist, who was blinded to the athletic history of the participants, carried out all measurements.

7 CONCLUSIONS

The main goal of this thesis was to evaluate relative and absolute reliability of the Agility Test for Adults and to indicate the determinants of agility capacity in physically inactive or active women and men, as well in male former elite athletes and their controls. The measures of physical functioning were described in the ICF framework.

The main findings and conclusions of the thesis can be summarized as follows:

1. The results of the new agility test, ATA, showed to be reliable and stable in untrained middle-aged people. The study determined the minimal detectable change required to detect an effect of exercise training, physiotherapy and rehabilitation. The ATA showed to be suitable for the studied groups of untrained middle-aged people, as well for the most of former elite athletes aged 66–91 years who was able to participate in the study. ATA test is challenging enough also for fit people (test track of 10.5 m, varying distance between foot marks, accelerating speed of execution towards end) and it does not include a ceiling effect.

2. Only below 25% of the agility capacity could be explained by the explosive force of leg muscles (standing long jump) having greatest explanatory power among physically inactive or active middle-aged people. It seems that BMI does not play an important role in agility.

3. In the cohort of male former elite athletes aged 66–91 years, the explosive force (jumping height) and age were the main determinants of agility capacity regardless of previous physical activity for three months or type of earlier competition sports. The four strongest determinants (jumping height, age, self-reported balance confidence and self-rated health) were able to explain about one-quarter of the agility capacity in this elderly study group. It can be suggested that the athletes' self-reported average physical activity or career of competitive training and racing, other personal factors or body functions did not appear to provide additional explanatory power on execution of agility among elderly men. According to this data, ATA could be used among relatively healthy men up to 80 years of age.

4. A former elite athletic career interrelated with the greater explosive force production of lower extremities at old age among former elite power athletes. However, this did not reflect a better agility capacity among them. The former elite athletes and the controls did not differ from each other in agility because the ATA was probably too demanding and difficult to execute for a part of these age groups. Neither the other objective tests of mobility, hand grip strength, nor self-rated balance confidence discriminated these study groups.

5. The ICF was found to be useful in describing the physical functioning of the study groups. The present study categorized determinants of agility by ICF. The findings of our study allow to link the measurement method of agility on component level 2 called ‘Activities’ (capacity) including action of mobility. By using responsive measures, it is possible to identify early signs of the declined agility characteristics in order to plan suitable exercise programs focused to maintain or improve the capacity of agility.

8 FUTURE DIRECTIONS

Agility is one of the basic functions of physical functioning required to safely execute activities of daily living, e.g. walking on a congested street, moving around in a crowed shopping centre and walking at home without colliding with furniture or stumbling on the mat. After all, there are few studies on capacity of agility and assessing the determinants of agility among middle-aged and older people. In the future, the capacity of agility and the meaning of agility in physical functioning should be studied among the general population. The ATA used in this thesis was comprehensive, reliable and feasible to evaluate the capacity of agility for field testing. However, data collected from a larger study population and from groups of people of different age and level of physical activity to obtain reference values are required. For example, it would be interesting to evaluate the determinants of the ATA among active sportswomen or -men during young adulthood and their matched controls. Furthermore, the validity of the ATA should be determined.

The development of the ATA should be continued. This would mean that an electronic or web-based form of the ATA with built-in computing would be even more practical and modern than a test track built on the floor with tapes. This would make it possible for anyone to practice agility who wants to do so.

Findings of this study strengthen the opinion that the ATA also demands other physical and cognitive characteristics that are now being measured, and their part in explaining agility results may be relatively great in the unexplained factor group. It would be worthwhile to conduct a study on the relationships between the ATA and the tests of cognitive and decision making function.

The physical activity questionnaires employed in this study could be directly applied in a clinical environment. The relationship between agility and LTPA were analysed by a two-dimensional scale (Study II) and by METh per week (Studies III and IV). A two-dimensional scale is neither very sensitive in adult people, nor does the conversion of information from LTPA give actual amounts of the volume of LTPA in older population. The development of cost-effective and sufficiently accurate tools for evaluating the intensity and the volume of total physical activity and its subcategories in clinical settings is required. Then it is possible to clarify the dose-response of physical activity defined as MET-minutes per week or type, frequency, duration and intensity. It would have been useful for the interpretation of the results if information on the physical activity profiles during childhood and specific details on the training programs of the sports groups had been available. Further research is needed to understand the association between body functions and/or activities and exercise history.

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